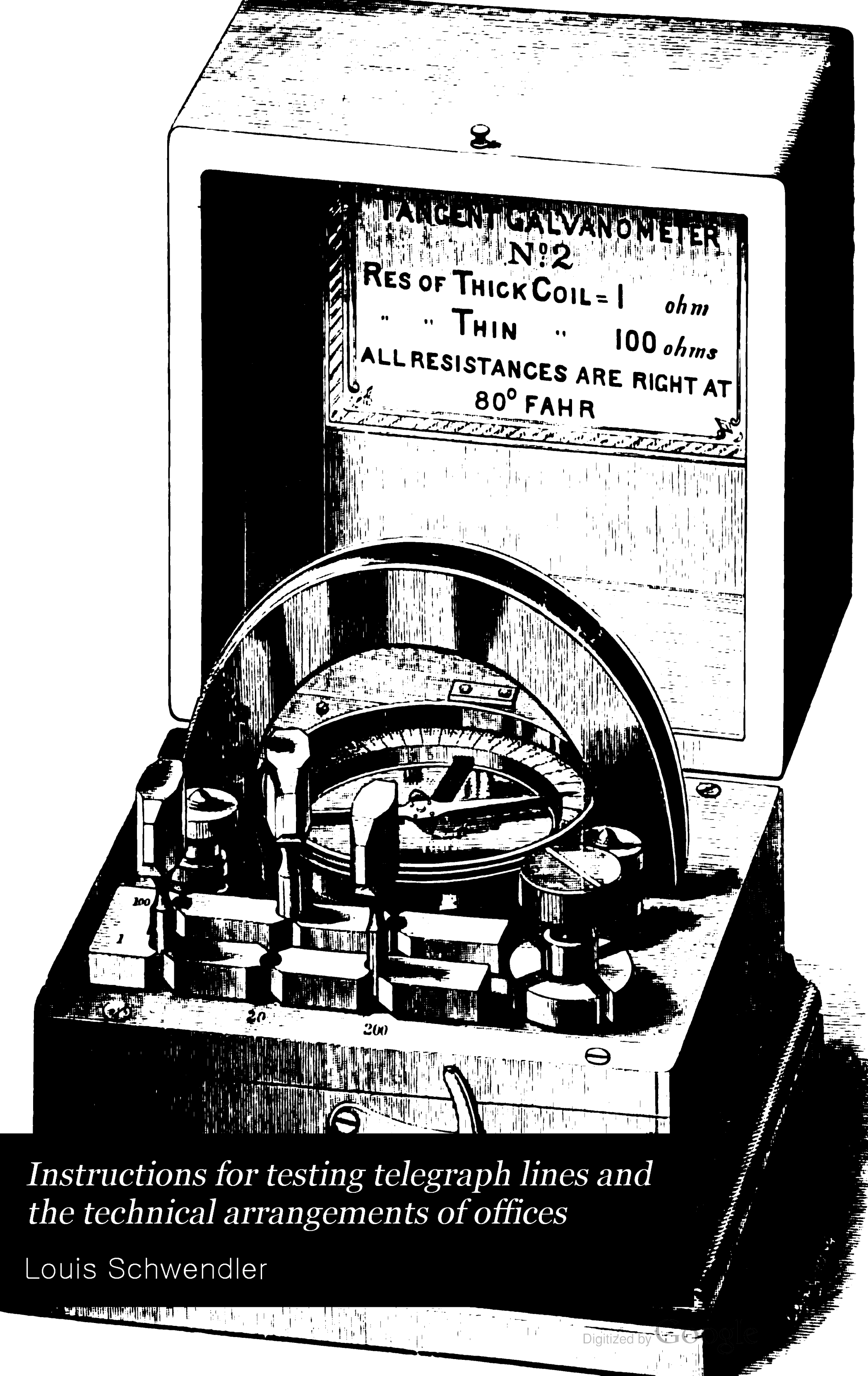
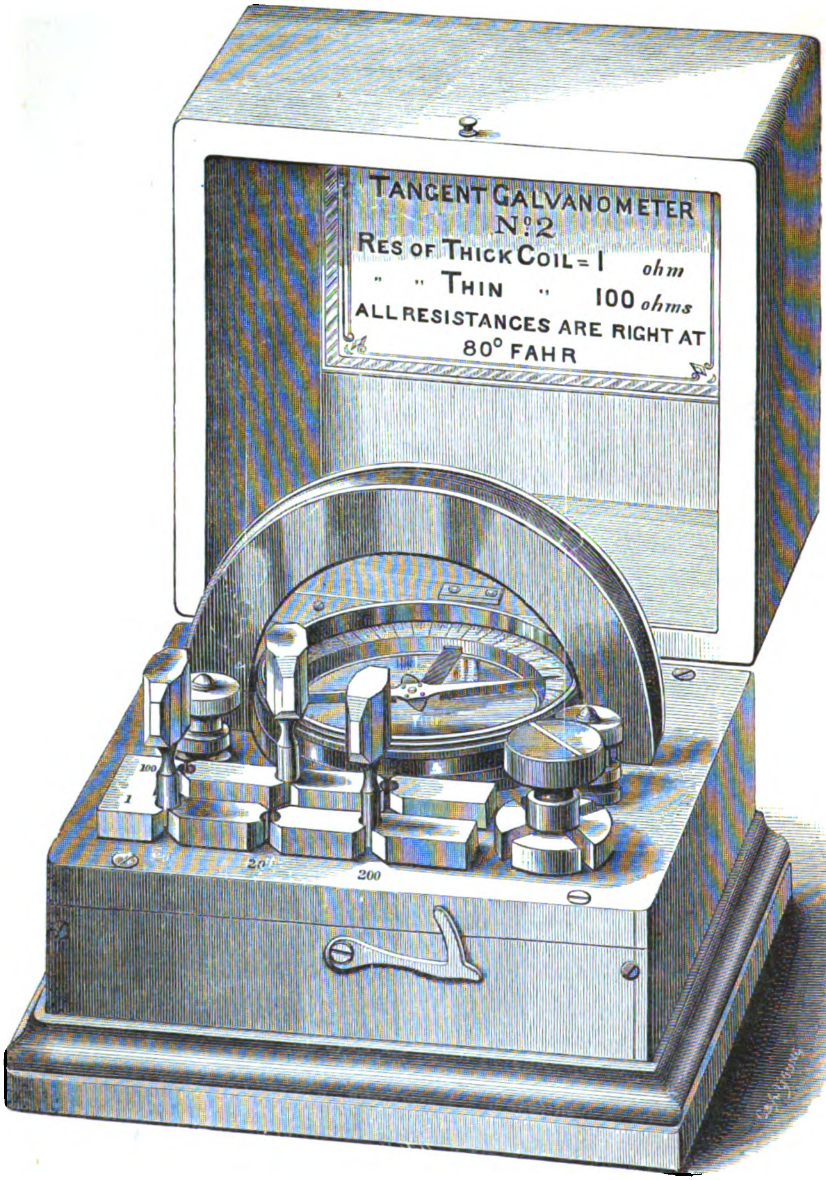

TANGENT GALVANOMETER
Nº2
RES OF THICK COIL = 1 ohm
" " THIN " 100 ohms
ALL RESISTANCES ARE RIGHT AT
80° FAHR
100
1
20
200

INSTRUCTIONS

FOR

TESTING TELEGRAPH LINES.

Ballantyne Press
BALLANTYNE, HANSON AND CO
EDINBURGH AND LONDON



THE TANGENT GALVANOMETER.—*P.* 2.

INSTRUCTIONS

FOR

TESTING TELEGRAPH LINES

AND THE

TECHNICAL ARRANGEMENT OF OFFICES.

ORIGINALLY WRITTEN ON BEHALF OF THE GOVERNMENT OF INDIA UNDER THE ORDERS OF THE DIRECTOR-GENERAL OF TELEGRAPHS IN INDIA.

BY

LOUIS SCHWENDLER.

VOL. II.

Second Edition,

AUTHORISED BY H.M. SECRETARY OF STATE FOR INDIA IN COUNCIL.

LONDON:
TRÜBNER & CO., LUDGATE HILL.
1880.

INTRODUCTION.

THE Introduction to the *first* volume of these *Testing Instructions* contains everything that it is necessary to know concerning the history and aim of the work at issue. Therefore I need only state here that the *second* volume is especially intended to supply *Testing information* to the officers in charge of Telegraph Stations, for whom the more complete but also more expensive Testing Apparatus (Bridge or Differential Galvanometer) is not made available; but who have to perform their Testing duties by the aid of the Tangent Galvanometer described in the beginning of the present volume.

The first and second Official Editions of my work (published in India by order of Government) contain some matters which, to a certain extent, are foreign to a book termed "Testing Instructions." The practical value of a work of this kind is manifestly its *compactness* and *straightforwardness* of solving Testing questions. I have thought it therefore better to leave out everything from the present *public* edition which does not refer to *Testing* pure and simple, and to add only such subjects as are not usually to be found in Textbooks or elsewhere. In Appendices I have endeavoured to give some fuller information on some of the most important subjects treated in the text. That this book has little or no similarity to other works on Telegraphy, is simply due to the fact that it was written in order to

endeavour to introduce a general system of Testing. I had never the ambition to write a book, but in my official position I was compelled to draw up instructions for the guidance of officers, and thus was led most naturally into investigating many questions to which otherwise attention is not generally drawn. An experience of upwards of ten years in India has sufficiently testified that with this second volume in hand, and a Tangent Galvanometer at disposal, any officer of the Department should be able to execute testing to the satisfaction of practical requirements, and even to obtain results of some physical value.

I believe, therefore, I am not sanguine in thinking that the second volume may also prove useful to other Telegraph Administrations, especially as I have read such encouraging general criticisms of the first volume, and have also received special acknowledgments from many of the Heads of Telegraph Administrations, all testifying to the practical usefulness of the first volume.

In conclusion, I feel it my duty and pleasure to express my thanks to Professor M'Leod, of the Royal Indian Engineering College (Cooper's Hill, England), for the very great trouble he has taken in seeing the second volume through the Press. Professor M'Leod has carefully recalculated *all* the numerical results, and by it has eliminated many errors which had crept into the two former editions. He has also added an index, which, it is hoped, will prove useful to readers.

LOUIS SCHWENDLER.

CALCUTTA, 1st *November* 1879.

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ERRATA.

Page 70, nine lines from top, *for* "*in*" *read* "*on.*"

„ 113, five lines from bottom, *for* "constant" *read* "correct."

„ 113, top line of note, *for* "*n*" *read* "*U.*"

„ 162, seven lines from top, *for* "·06986," *read* "3164·3."

„ 162, nineteen lines from top, *delete* "per second."

PART III.

INSTRUCTIONS FOR TESTING THE TECHNICAL ARRANGEMENTS OF OFFICES.

THIS Part is a consolidation and extension of the technical circulars that have been issued to the Department since the beginning of 1869. It may be most naturally divided into two sections, treating of—

I. BATTERIES.
II. INSTRUMENTS AND CONNECTIONS.

It is assumed that the tests mentioned in this Part are executed with the Tangent Galvanometer specially designed for the purpose. An explanation of the form, theory, and use of this instrument will therefore be necessary in the first place.

PRELIMINARY.

THE testing instruments fully described in Vol. I., which are used for line testing, will also answer for testing the *technical arrangements* of signal offices; but they are too expensive and unnecessarily delicate for general use. At the same time it appeared very necessary that every Telegraph Station should have some means of executing

quantitative measurements; and for this purpose a cheap Tangent Galvanometer, of convenient form and special construction, has been introduced.

THE TANGENT GALVANOMETER.

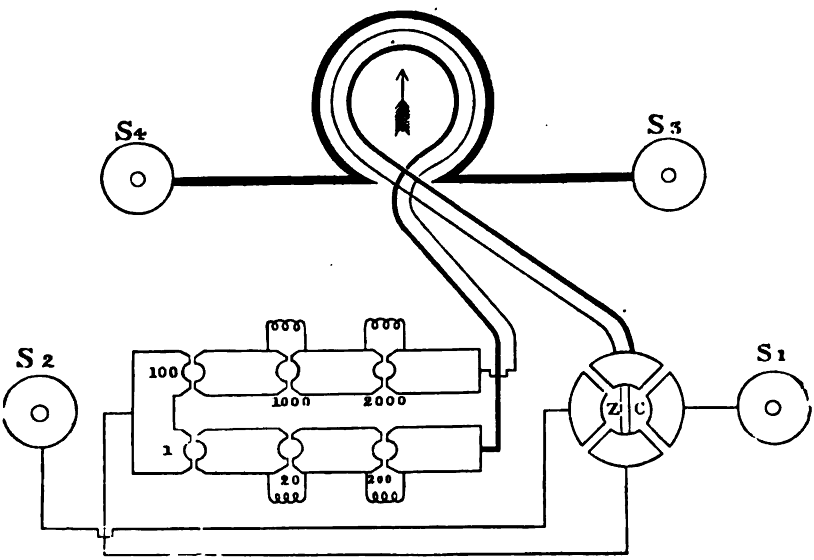
This instrument was specially designed by me in 1870 to render possible the execution of quantitative measurements, for the purpose of ascertaining and maintaining the normal electrical condition of the Telegraph offices throughout India. Such an instrument, therefore, to be practicable, must combine cheapness and portability with sufficient accuracy of measurement. An experience extending over more than nine years, during which time about 142 galvanometers have been manufactured in the workshops, and issued to the Department, in addition to twenty received from England, has proved that this instrument satisfactorily fulfils the desired conditions.

Whilst it is true that there are many kinds of defects which may be detected by simple ocular inspection, and in fact may be rendered impossible of occurrence by a proper and careful fitting up of the offices, still it is requisite to supplement this inspection from time to time by quantitative measurements, for in the course of time changes necessarily occur in batteries, earths, connections, instruments, &c., which may interfere with their efficiency, and which cannot be discovered without quantitative measurements.

There is not the slightest doubt left in my mind that the progress of Telegraphy in every country will depend to a very great extent on the initiation of a quantitative test system. If testing be executed in the true physical spirit, it will never interfere with traffic, but will increase its efficiency. This is not an assumption, but has been practically proved in India during the past nine years.

§ I. *Description of the Tangent Galvanometer.*
Figure 1 exhibits the general plan of this instrument.

Fig. 1.



This instrument has three separate deflecting coils, viz., the *brass ring*, marked in fig. 1 (▬). This ring is simply cut open, and the two ends are brought in contact with the terminals S_3 and S_4. The resistance of the brass ring is nil. It can only be used as the deflecting coil when the current exceeds ·5 Oersted. The *thick coil*, marked in fig. 1 (——), consists of a few convolutions of thick copper wire, the total resistance of which is approximately one ohm. In the circuit of the thick coil resistances 20 and 200 can be inserted, and the stopper (1) acts as key. The *thin coil*, marked in fig. 1 (—), consists of a larger number of convolutions of thin copper wire, offering about 100 ohms resistance. In the circuit of the thin coil resistances 1000 and

2000 can be inserted, and the stopper (100) acts as the key. Both the thick and the thin coils are in connection with the terminals S_1 and S_2, and contain in circuit the reverser (C Z), by which the direction of the current through the instrument can be conveniently changed. In order to make the measurements as nearly as possible correct, the magnet needle has a length less than one-fifth of the diameter of the coil. At right angles to the magnetic axis of the needle is fixed an aluminium index, 2½ inches long, by which the deflections are read. In transport the needle should be removed from the pivot, and packed up in the little box which fits into the galvanometer case. In the latest instruments one side of the dial is graduated in tangents, so that the currents passing are directly proportional to the deflections read in this scale. For use in exact calculations, a memorandum is provided with each instrument, giving the exact resistances of the galvanometer and standard coils.

§ II. *Theory of the Instrument.*

The coils of the instrument being set in the plane of the magnetic meridian, and the needle being in a uniform magnetic field, i.e., ***under the influence of the earth's magnetism alone, the strength of a current passing is approximately proportional to the tangent of the angle to which the needle is deflected.*** (*See* Appendix I.)

It is clear, therefore, that when measuring with a tangent galvanometer, no magnets or iron which may influence the needle should be near the instrument. In Telegraph offices where so many instruments containing iron and permanent magnets are in use, it must first be ascertained that they have no sensible influence on the needle. This is best done by moving the iron or magnet, or the instrument that contains them, starting from its actual position, in a circle round the tangent galvanometer, when the needle should remain unaffected through-

out the revolution. Further, the best deflections for observation are those of about 45°. Above 45° the tangents increase very rapidly with the angle, and consequently the unavoidable observation error will throw out the result very much; and, besides, the tangent law is more rigorously true for small than for great angles. Under 45° the observation error, which may be taken as constant, becomes a sensible fraction of the whole deflection, and has therefore a large *percentage* influence.*

If we now designate by C the current which deflects the needle, and by H the horizontal component of the

* Observations of whatever kind can never be made with perfect accuracy, and consequently the quantities that have to be determined from the observations must always be subject to more or less error. Hence in every branch of experimental investigation, it will be at once clear, the first endeavour should be to arrange and conduct the experiments in such a manner that, with the available means, the unavoidable observation errors shall have the least possible quantitative influence on the final results. By what means this desirable end is to be attained, and to what extent its application will be successful, will depend, of course, on the special circumstances of each particular case, *i.e.*, on the nature of the observations themselves, on the method of observing adopted, and on the laws which connect the quantities to be determined by experiment with those that are thence to be found by calculation. In our particular case we have to compare currents, by reading deflections, and thence calculating their relative values by means of the law of tangents. Now, it will be at once seen, that there is one particular angle which will be best for reading the deflection. For, say we read a deflection near 90°, then the smallest error will relatively have the greatest weight, and throw the result out considerably, on account of the rapid variation of the tangents with the angles towards this point; that is, even though the error in itself may be small, its *importance* will here be greatest, and therefore readings of deflections in the neighbourhood of 90° should be avoided. Suppose, again, we take the reading near zero: then, it is true, the tangent varies here but slowly with the angle; but the influence of the observation error on the final result will, nevertheless, be again considerable, for within however narrow limits we may reduce the magnitude of the error, it will yet constitute a considerable fraction of the angle observed, on account of the smallness of the whole angle itself. Hence readings of deflections in the neighbourhood of zero are to be also avoided. Between 0° and 90°, then, there must be at least *one* angle where the

earth's magnetic force at the place of observation, we have

$$K\,C = H \tan a^{\circ}$$

where a° is the deflection of the needle and K is the coefficient of the instrument, which remains constant so long as the coils of the galvanometer are not changed. Of H it is to be remarked that it is variable with the locality of the observation, but for successive observations taken in the same place it is to be regarded as constant; while K depends entirely on the individual instrument itself—its form and dimensions.

As in our case the instrument is used only for com-

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influence of the reading error will be a minimum. That there is one, and only one, angle—*viz.*, 45°—can be proved as follows:—

We have $$C = \frac{H}{K} \tan a^{\circ}$$

$\therefore$ $$\frac{d\,C}{d\,a} = \frac{H}{K} \sec^2 a^{\circ}$$

$$= C \frac{\sec^2 a^{\circ}}{\tan a^{\circ}}$$

Whence $$\frac{\delta\,C}{C} = \frac{\delta\,a}{\tan a^{\circ} \cos^2 a^{\circ}} = \frac{\delta\,a}{x} \text{ say.}$$

Now the condition of the observation error $\delta\,a$ having the least influence on the result will obviously be fulfilled by making the ratio $\frac{\delta\,C}{C}$ a minimum; that is, for any given $\delta\,a$, by making x a maximum.

Thus $$x = \tan a^{\circ} \cos^2 a^{\circ}$$

$$= \sin a^{\circ} \cos a^{\circ}$$

$$\frac{d\,x}{d\,a} = \cos^2 a^{\circ} - \sin^2 a^{\circ} = 0$$

$\therefore$ $$\sin a^{\circ} = \cos a^{\circ}$$

Whence $$a = 45^{\circ}$$

paring currents, and not for measuring their absolute magnitude, a knowledge of the two constants H and K is not required. For let C and C' denote two currents, which at the same place of observation, measured with the same instrument, give respectively deflections of a° and a'°, then we have the two equations

$$KC = H \tan a^\circ$$

$$KC' = H \tan a'^\circ$$

Whence $$\frac{C}{C'} = \frac{\tan a^\circ}{\tan a'^\circ}$$

which shows that the currents are to one another simply in the ratio of the tangents of the deflections they produce.

Further $$C = \frac{E}{f + g + w}$$

and $$C' = \frac{E'}{f' + g + w'},$$

where E and E' are the electromotive forces of the batteries producing the currents C and C', and f and f' are their internal resistances; g is the resistance of the galvanometer coil; and w and w' are any resistances in the circuit external to the battery and galvanometer.

Hence $$\frac{C}{C'} = \frac{f' + g + w'}{f + g + w} \cdot \frac{E}{E'}$$

$$\therefore \quad \frac{f' + g + w'}{f + g + w} \frac{E}{E'} = \frac{\tan a^\circ}{\tan a'^\circ} \quad \ldots \quad \ldots \quad (1)$$

This is the general formula for a tangent galvanometer when employed for comparative measurements only, and from it the several formulæ required in particular cases can be deduced, as will be seen by the subsequent application of the instrument.

§ III. *Tests of the Condition of the Tangent Galvanometer.*

1. *Needle and index.*—In the first place, the needle with its pointer should be quite free to swing and spin round when a strong current passes through the coil. The pointer ought to move over the dial as close as possible to it, without touching it, in order to avoid parallax. The axis of the pointer should be straight, *i.e.*, when one of its ends is adjusted to zero on one side, its other end should point also to zero on the other side. The axis of the index should be at right angles to the magnetic axis of the needle. This will be the case when the same current with its direction reversed gives equal deflections on opposite sides of the zero point. When these conditions are fulfilled, the coils of the galvanometer can be set in the magnetic meridian by simply turning the instrument so as to adjust one end of the pointer to zero.

2. *Magnetism of the needle.*—This is by no means a constant quantity. High temperature, the direct rays of an Indian sun, and strong currents may reduce the original magnetism of the needle considerably; and since it is necessary that it should be sufficiently strong to overcome the unavoidable friction on the pivot, so that the needle may return accurately to zero after having been deflected, it should be tested from time to time, and when necessary the needle re-magnetised. To ascertain the strength of the magnetism, the time required by the needle to execute a given number of oscillations, under the influence of the earth's magnetism alone, must be found. All magnets having been removed from the neighbourhood of the instrument, and the pointer having been adjusted to zero, send a current through the thin coil of the galvanometer sufficiently strong to start the needle spinning round, and begin to

count after the needle has ceased to spin and commenced to swing to and fro. By one oscillation is understood the motion of the needle from its limiting position on the one side of the zero point, through the zero point, to its limiting position on the opposite side. At the moment of passing through the zero point the velocity of the needle will be greatest, and therefore this is the best point to watch; and the time occupied by a certain number of oscillations can be most accurately found by observing the time required for the needle to pass through the zero point a given number of times. Any needle of the size and pattern used in the galvanometer should not make less than seven oscillations in ten seconds. If it make less, it must be re-magnetised. [The needles of the recent instruments have aluminium vanes attached to them to act as dampers. These will not, of course, oscillate so rapidly. Hence these vanes have to be taken off before making the test; or, as this may be inconvenient, the test of the sufficiency of the needle's magnetism must be its gradual and accurate return to the zero after having been deviated.]

3. *The mechanical state of the pivot and agate cap of the needle.*—To ascertain this, spin the needle round as before, and begin to count *immediately* the needle ceases to spin and commences to swing to and fro, and continue to count until the needle comes to rest. The total number of oscillations executed by any needle, whose magnetism has previously been tested as above, should not be less than fifteen; and with such a needle the pointer should always return to the zero exactly when the oscillations cease. Badly shaped or rusty pivots and dirty caps can be the only sources of undue friction; and these faults, when found to exist, must be at once remedied. Rust on the pivot is best removed by the careful use of a little chalk and oil. On no account must emery or sand-paper

be used. The agate, when dirty, must be cleaned out with a rag tied round a pointed body, such as a wooden match cut to a point; but great caution must be used not to injure its surface.

If the pivot be broken or bent, it can be repaired or replaced by any bazaar watchmaker.

4. *Sensitiveness of the tangent galvanometer.*—The standard cell * should give:—

Through thin coil and 2000 ohms, deflection of 5°.
Through thin coil and 1000 ohms, deflection of 10°.
Through thin coil and no ohms, deflection of 55°.
Through thick coil and 200 ohms, deflection of 4°.

The reading obtained through the thick coil with the "200" plugged up will depend on the internal resistance of the cell used—a very variable quantity. The other three deflections, however,—especially that with the thin coil and "2000" in circuit,—depending on the electromotive force of the cell only, which of course is sensibly constant for all cells in good order, may with advantage be used to control the galvanometer.

5. *Resistance of the tangent galvanometer and resistance coils.*—This is a test which will be very rarely required, since under ordinary circumstances wire coils do not perceptibly alter their resistance in time. However, it might become necessary to control their resistances, and therefore the best method should be known. It will, however, be better to state this method after the explanation of the use of the galvanometer. (*See* § V.)

§ IV. *On the Use of the Tangent Galvanometer.*

The instrument may be employed in four different

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* *See* Section I.

ways, viz. :—For measuring currents, resistances, comparing electromotive forces, and receiving signals.

1. *The measurement of currents.*

A tangent galvanometer is one of the most convenient instruments for accurately measuring electric currents, *i.e.*, to express them in terms of any one current which has been adopted as the *unit current.* It has been shown that for one and the same coil of the tangent galvanometer, and at the same locality, the following relation holds good :—

$$\frac{C}{C'} = \frac{\tan \alpha^\circ}{\tan \alpha'^\circ}$$

or,

$$C = C' \frac{\tan \alpha^\circ}{\tan \alpha'^\circ}$$

If we now give to C' such a value that $\alpha' = 45^\circ$, we have $\tan \alpha' = \tan 45^\circ = 1$, and therefore more simply,

$$C = C' \tan \alpha$$

Consequently if we know C' in terms of any one recognised unit of current, we could express in the same terms any other current C which gives a deflection α.

The current C' which produces the deflection 45° is best found by experiment. For instance, we find that a battery consisting of ten Minotto cells connected in series, gives through the thin coil of the tangent galvanometer, with 2000 ohms in circuit, a deflection of 47°. The resistance of the battery was accurately measured and found to be equal to 160 ohms.

The value of this current (C'') in $\frac{\text{minotto}}{\text{ohms}}$ is

$$C'' = \frac{10}{160 + 2000 + 100} = 4425 \times 10^{-6}$$

Now C' we can easily calculate, thus—

$$\frac{C'}{C''} = \frac{\tan 45^\circ}{\tan 47^\circ}$$

Therefore $$C' = \frac{C''}{\tan 47^\circ} = \frac{4425 \times 10^{-6}}{\tan 47^\circ}$$

$$= 4126 \times 10^{-6}$$

Hence we can ascertain the strength of any current in $\frac{\text{minotto}}{\text{ohms}}$ which produces a deviation of a° in this particular galvanometer by means of the formula—

$$C = 4126 \times 10^{-6} \tan a$$

In exactly the same manner may be obtained the value of the current in $\frac{\text{minotto}}{\text{ohms}}$,* which would produce 45° deviation through the *thick coil* or through the *brass ring* of the given galvanometer.

Considering that readings taken between 10° and 70° are sufficiently correct, and that we may employ either the *thin* or the *thick* coil or the *brass ring* for measuring currents, the limits of measurement of the tangent galvanometer are from about 0·5 to about 7000 Milli-Oersteds. When using the *brass ring* as the deflecting coil, the great practical difficulty will always be the direct action of the leading wires on the needle, which

---

* Practically we may call this unit of current $\left(\frac{\text{minotto}}{\text{ohm}}\right)$ the *Weber per Second*, or, as the late Mr. Brough has proposed, the *Oersted;* for the determinations of the resistance unit, and of the E. M. F.'s of galvanic elements in absolute measure, by different physicists, are still so different from each other, that it appears justifiable to make this substitution. Probably, however, a $\frac{\text{minotto}}{\text{ohm}}$ is somewhat greater than a *Weber per Second* or an *Oersted.*

action cannot be made small as compared with the action of the ring itself. Hence, if it is impossible to make the direct action of each leading wire nil, we must try to neutralise their action on the needle. This can always be approximately achieved by placing the leading wires in the horizontal plane in which the needle swings, and also parallel with the ring. Then taking $\pm$ readings with a *constant* current, and judiciously bending the one or the other or both of the two leading wires will bring the $\pm$ deviations very close together, when the mean of the two tangents will give a sufficiently accurate measure of the current.

2. *The measurement of resistances.*

Firstly: *The internal resistance of batteries.*

Connect the two poles of the battery to the terminals S_1 S_2 of the instrument, and observe at least two deflections with different resistances in circuit.

In the general equation (1.) putting

$$E' = E$$

$$f' = f$$

and developing f, we get

$$f = \frac{w' - w \dfrac{\tan a^\circ}{\tan a'^\circ}}{\dfrac{\tan a^\circ}{\tan a'^\circ} - 1} - g \quad \dots \quad \dots \quad (2)$$

Generally, signalling batteries consist of a large number of elements, and therefore the two requisite deflections, a° and a'°, must be invariably taken through the thick coil, as the deflection through the thin coil without any external resistance would be too large. When measuring with the thick coil, there are three different values that may be given to w and w', namely, 0, 20 ohms, and 200 ohms. So long as the deflection through the thick

coil and $w = 0$ does not exceed 70°, it is most convenient for calculation to take $w = 0$.

Thus putting $w = 0$ in equation (2.), we have

$$f = \frac{w'}{\frac{\tan a^\circ}{\tan a'^\circ} - 1} - g$$

which may be written

$$f = \frac{\tan a'^\circ}{\tan a^\circ - \tan a'^\circ} w' - g \quad \ldots \quad (3)$$

Further, which is the best value—20 ohms or 200 ohms—to give w' in the second observation depends upon circumstances, *i.e.*, the larger f is the larger w' should be taken.

To eliminate the errors of zero point and reading, it is advisable to take all readings with reversed currents through the galvanometer, and take the mean of the two observed angles as the true angle. The expression for f may be written

$$f = zw' - g$$

where

$$z = \frac{\tan a'}{\tan a - \tan a'},$$

is a factor depending only on the values of the deflections obtained with two observations. Hence by coordinating different values of a and a' we can calculate a table *once for all*, which will give directly the value of z for any pair of angles, and thereby greatly reduce the labour involved in ascertaining the resistance of a battery. (*See* Appendix II.)

EXAMPLE.—*Required the resistance of a battery of* 10 *Minotto elements connected in series.*

By experiment we find

	+	−	mean.
$a =$	70	71	70·5
$a' =$	32	32	32·0

the second observation (deflection $= \alpha'^{\circ}$) being taken through $w' = 200$ ohms.

Now from the table of tangents we ascertain that

$$\tan 70 \cdot 5^{\circ} = 2 \cdot 824$$

Further $$\tan 32^{\circ} = 0 \cdot 625$$

Hence $$f = \frac{0 \cdot 625 \times 200}{2 \cdot 824 - 0 \cdot 625} - 1 \text{ ohms.}$$

$$= 56 \cdot 9 \text{ ohms.}$$

Therefore the average resistance per cell

$$= 5 \cdot 69 \text{ ohms.}$$

If the measurements have been made very accurately, and if it be required to know the resistance f as correctly as circumstances will permit, we must employ the true values of g and w' as given in the memorandum, and corrected to the temperature of the test.

For instance, say that

$$g = 0 \cdot 91 \text{ ohm at } 80^{\circ} \text{ Fahr.}$$
$$w' \text{ (marked "200" ohms)} = 198 \cdot 2 \text{ ohms at } 80^{\circ} \text{ Fahr.}$$

and that the test is made at 107° Fahr.

The resistance of copper wire increases 0·00215 of itself per degree Fahrenheit of increase of temperature; while the resistance of German silver increases at about one-tenth of this rate.

Therefore at

107° Fahr., g becomes $= 0 \cdot 96$ ohm

and w' „ $= 199 \cdot 45$ ohms

whence $f = 55 \cdot 72$ ohms.

Secondly: *An electrical resistance which does not contain an electromotive force.*

This is the case when determining a wire resistance,

such as that of instruments; and it is clear that an appropriate testing battery is requisite, the internal resistance of which must be known. Further, it will also be obvious that, whatever the absolute magnitude of the unknown resistance which is to be measured may be, it will be always best to take the one reading through the unknown resistance *alone* (without introducing any other electrical resistance), and the other reading through a known resistance *alone* (without having the unknown resistance in circuit), since it is only under these conditions that the battery power required will be a minimum, which is always desirable, not only on practical grounds, but also for theoretical reasons, as will be made clear hereafter.

Thus we have

$$\tan a^\circ \propto \frac{E}{g + x + f}$$

(reading through the unknown resistance x only),

$$\tan a'^\circ \propto \frac{E}{g + w + f}$$

(reading through the known resistance w only),

$$\therefore \quad \frac{\tan a^\circ}{\tan a'^\circ} = \frac{g + w + f}{g + x + f}$$

and developing x,

$$x = \frac{\tan a'^\circ}{\tan a^\circ} (g + w + f) - (g + f) \qquad (4.)$$

This expression for x will under all circumstances give the most accurate results, and a more general one is not required.

Disregarding at first the error introduced by the reading of a and a', the accuracy of x depends on the exactitude with which f is known.

First, regarding f as in itself perfectly constant, its

magnitude as determined by experiment will nevertheless contain a certain error, at least proportional to f itself, and therefore, to make its influence least, f should be very small in comparison with g, when f would also be small in comparison with $g + w$.

On the other hand, however, it is a well-known fact that a galvanic battery varies in resistance and electromotive force far more rapidly if its internal resistance is small (in virtue of polarisation by the current), and therefore, on the ground of constancy, it would be better to make f large. Thus all that can be said is that the resistance of the testing battery should be as small as practicable, without endangering its constancy during the measurements. Further, as the resistances that may have to be measured vary within wide limits, it is clear that, even testing with one and the same coil, the selection of the testing battery, when very accurate measurements are desired, will entirely depend on the magnitude of the resistance to be measured. By connecting a given number of elements in series or parallel, the tester has it conveniently in his power to alter the electromotive force and internal resistance of the testing battery according to the special requirements of the case.*

As a general rule, f and E should be small when x is small.

In any case, however, to be able to judge of the accuracy of the results obtained, it is necessary to measure f before and after the determination of x. Then the varia-

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* When a small resistance is to be measured, the internal resistance of the battery must be low. If Minotto cells are to be employed, then the battery resistance should not be reduced by using cells of individually low resistance (which may vary through polarisation during the tests), but by joining up parallel a sufficient number of cells of about 20 ohms resistance each. The internal resistance can be thus reduced to any required extent, and at the same time polarisation almost avoided.

tion of f will give a fair idea of what degree of accuracy may be expected in the value of x.

In fact, it may be mentioned here that results obtained by experiments have scarcely any real signification, if the tester himself does not adopt some means of checking their accuracy. No matter how large the error in results may be, if its magnitude be approximately ascertained by reasoning or calculation, the results will still always possess a real value. This is a most important point even when measurements are made for practical purposes and not with any intention of scientific research, and therefore the question of determining the accuracy of results should always be fully gone into.

Formula 4 shows also that the accuracy of x depends on the accuracy of the ratio $\left(\frac{\tan a'^{\circ}}{\tan a^{\circ}}\right)$ *i.e.*, of the readings, and it has been proved before that observation errors in the readings have the least effect on the final results if they are made at 45°, whence it follows that

$$a = a' = 45$$

or, $\quad x = w \quad$ would be best.

As, however, the values of w, the fixed known resistance that can be put in circuit with the galvanometer, are very limited in number, the circuit of the thick coil containing four, namely :—

$$\left.\begin{array}{l} w = \quad 0 \\ w = \quad 20 \text{ ohms} \\ w = \ 200 \quad ,, \\ w = \ 220 \quad ,, \end{array}\right\} \text{approximately,}$$

while that of the thin coil also contains four, namely :—

$$\left.\begin{array}{l} w = \quad 0 \\ w = 1000 \\ w = 2000 \text{ ohms} \\ w = 3000 \end{array}\right\} \text{approximately,}$$

it follows that the above condition

$$x = w$$

can only be nearly fulfilled when measuring resistances approximately equal to these eight fixed resistances, so that it will not generally be possible. However, low resistances can always be measured more accurately with the thick coil, and high resistances with the thin coil; and, considering that resistances have to be measured with the tangent galvanometer from the fraction of an ohm up to more than 3000 ohms, we may ask which resistance between the two given limits can be measured with equal accuracy with either galvanometer coil?

This limit is about 350 ohms; or all resistances under 350 ohms should be measured with the thick coil, and above 350 with the thin coil. The superior limit of battery power to be employed with the *thick* coil may be taken at ten cells, and the inferior limit of the battery power to be employed with the *thin* coil at two cells.

EXAMPLES.—1. *Required the resistance of a sounder.*

As it is known that a sounder has a resistance of about 30 ohms, the readings must be taken through the thick coil. Now we have to select the proper testing battery to get deflections of about 45°.

We know that the standard cell (resistance = 16 ohms) gives with the particular tangent galvanometer 6° with the 200 ohms in circuit.

Therefore $$\tan 6^\circ \propto \frac{E}{16 + 1 + 200}$$

Let y be the number of cells required for the test,

then $$\tan 45^\circ \propto \frac{y\,E}{16y + 1 + 30}$$

$$\therefore \quad \frac{\tan\ 6^\circ}{\tan 45^\circ} = \frac{31 + 16y}{217y}$$

which gives $$y = 4{\cdot}554, \text{ say } 4.$$

Now, determining first the resistance of the testing battery, we find $f = 52{\cdot}45$ ohms.

And then taking the two readings

	+	−	mean	
$a = 43$		43	43	through x alone
$a' = 48$		48	48	„ 20 ohms

After this make a second determination of the battery resistance, from which $f = 54{\cdot}21$ ohms.

Thus the best f to be taken for calculation is the mean

$$f = 53{\cdot}33 \text{ ohms.}$$

Substituting $g = 0{\cdot}98$

$w = 19{\cdot}75$

and, $f = 53{\cdot}33$

by formula (4.) we have

$$x = \frac{\tan 48^\circ}{\tan 43^\circ}(0{\cdot}98 + 19{\cdot}75 + 53{\cdot}33) - (0{\cdot}98 + 53{\cdot}33)$$

$$x = 33{\cdot}89.$$

The slight variation of f influencing the result in this case only in the first decimal place.

2. *Required the resistance of a relay.*

The resistance marked on the instrument is 1572 ohms at 80° Fahr., and it is suspected that there is something wrong with the coils, since the most careful adjustment fails to bring the instrument up to the standard of performance.

This resistance is to be measured through the thin coil.

The testing battery consists of ten Minottos connected in series, and has an internal resistance of $f = 200$ ohms.

Many previous experiments have shown the resistance of this battery to be very constant, it having scarcely altered one half per cent. during the previous fortnight, so that one determination of f will suffice.

Taking the two readings, we find

	+	−	mean	
$a =$	56	56	56	through the relay resistance
$a' =$	41	41	41	through the "2000"

Then substituting in formula (4)

$$g = 98\cdot2$$
$$w = 2001\cdot1$$
$$f = 200$$

we get

$$x = 1050\cdot5 \text{ ohms}$$

which is 521·5 ohms smaller than the marked resistance. It is therefore highly probable that the relay bobbins are partly shunted. The instrument is taken to pieces and the two bobbins tested separately, when it is found that one has a resistance of

780·2 ohms

while the other has only a resistance of

265·8 ohms
Total = 1046·0 ohms

which agrees within 0·4 per cent. with the previous determination of x. It is clear, therefore, that the second bobbin is partly short-circuited.

These two examples illustrate cases where the unknown resistance is not very different from the known resistance that can be introduced into the circuit. It may happen, however, that the resistance to be measured is either only the fraction of an ohm or very much greater than 3000 ohms, and for these two cases it will be advisable to give special examples.

EXAMPLE: 1st case.—*The resistance to be measured accurately is very small.*

Here the first question is clearly the selection of an

appropriate testing battery. The internal resistance of the testing battery must be so small that the resistance x to be measured cannot be neglected against it, and further so large that the reading through the small unknown resistance, when alone in circuit, does not exceed a certain angle. At or near 70° the tangents increase about 7 per cent. with each degree; and as careful readings must be correct at least within half a degree, the error introduced by a wrong reading at 70° cannot be much larger than 3 per cent. Thus we will fix 70° as the highest deflection to be admitted in the observations.

Now first ascertain, by taking two readings through the thick coil with the standard cell, the apparent magnitude of the resistance to be measured. From this suppose it to follow that x cannot be smaller than 0·5 ohm. Next the resistance of the testing battery which is required is to be found as follows.

The standard cell gives about 5° through the thick coil and 200 ohms resistance, while it has a resistance of 20 ohms.

Further, as the resistance to be measured is so very small, a testing battery of one cell will suffice.

Now $$\tan\ 5^\circ \propto \frac{E}{200 + 20 + 1} = \frac{E}{221}$$

and

$$\tan 70^\circ \propto \frac{E}{y + 1 + 0·5} = \frac{E}{1·5 + y}$$

$$\therefore \quad \frac{\tan\ 5^\circ}{\tan 70^\circ} = \frac{1·5 + y}{221}$$ where y is the resistance of the testing battery required.

Hence $$y = 221\,\frac{\tan\ 5^\circ}{\tan 70^\circ} - 1·5 = 5·54$$ about, say 5 ohms.

The testing battery we get by connecting two cells parallel of about 10 ohms resistance each.

First measure most accurately the resistance of each of the two cells to be joined up parallel, thus

Resistance of 1st cell = 9·00 ohms
„ „ 2d „ = 10·00 „

Next calculate the parallel resistance of the two, *i.e.*

$$f = \frac{9 \times 10}{19} = 4{\cdot}74 \text{ ohms}$$

which value of f is more correct than if it had been determined by a direct measurement.

Now take the two readings, thus

	+	−	mean	
$a =$	69	69	69	(with x in circuit)
$a' =$	34	34	34	(with 20 in „)

Then, substituting in formula 4,

$$g = 0{\cdot}98$$
$$w = 19{\cdot}82$$
$$f = 4{\cdot}74$$

we get

$$x = \frac{\tan 34^\circ}{\tan 69^\circ}(0{\cdot}98 + 19{\cdot}82 + 4{\cdot}74) - (0{\cdot}98 + 4{\cdot}74)$$
$$= 0{\cdot}893 \text{ ohm}$$

It is, therefore, clear that the more nearly the resistance to be measured approximates towards zero, the smaller the resistance of the battery must be made, and consequently the larger the reading through the unknown resistance alone will become—both facts necessitating the greatest care to get an accurate value of x, and limiting the application of the instrument with respect to the measurement of very low resistances. The calculation of the internal resistance of a compound cell from the known resistance of the simple cells, that connected

parallel form the large cell, will be always more accurate than measuring the resistance of the large cell directly, especially if the resistance be small. If a large number, n, of cells have to be connected up parallel to form a single large cell, and if it be known that the different cells have all about the same resistance (each giving almost the same deflection through the thick coil with $w = 0$), then it will be sufficiently correct to measure the total resistance of the n cells when connected up in series —say it is F—and divide by n^2, to get the resistance of the battery when the elements are joined up parallel to form one single cell, thus

$$f = \frac{F}{n^2}$$

This value of f, so long as the resistances of the single cells are not exactly equal, will be always somewhat larger than the true resistance; but this will do no harm, as in reading, when the large cell is closed through a small resistance, its resistance will have a tendency to become somewhat larger in virtue of polarisation.

2d case.—*The resistance to be measured exceeds very much the highest limit of the fixed resistances that can be inserted in the thin coil.*

Here, again, the first question is of the testing battery.

Put the unknown resistance in circuit with the thin coil, and increase the battery power until the deflection becomes readable, which we may fix safely at a minimum of 12°. Then take a reading through the 3000 coil, using the same battery if the deflection is not greater than 70°. If, however, the deflection through 3000 becomes greater than 70°, it is better to reduce the battery in the second reading, and assume that the electromotive forces are proportional to the number of elements used in each case. It follows that so long as the number of cells available is

unlimited, and so long as we may trust * that the ratio of two electromotive forces is equal to the ratio of the number of cells used, the magnitude of the resistance that can be measured with the tangent galvanometer has theoretically no limit. Practically, of course, it has, since the battery power available in an office is essentially limited.

EXAMPLE.—The reading through the thin coil and unknown resistance becomes 15° by using 200 elements connected up in series; while the reading through the 3000 coil with the 200 cells is over 80°, which is too high. Halving, then, the battery in the second case, we have

	+	—	mean	
$a =$	15	15	15	through the unknown resistance with $E = 200$
$a' =$	58	58	58	through 2000 ohms with $E' = 100$

and substituting in equation (1.)

$$E = 200$$
$$E' = 100$$
$$g = 100$$
$$w = x$$
$$w' = 2000$$
$$\left.\begin{array}{l} f' = 3000 \\ f = 1600 \end{array}\right\} \text{resistances of testing batteries as found by measurement}$$

Then $\dfrac{\tan 15^\circ}{\tan 58^\circ} = \dfrac{200}{100} \times \dfrac{100 + 3000 + 2000}{100 + 1600 + x}$

$\therefore \qquad x = 59219$ ohms.

3. *The comparison of electromotive forces.*

By the general formula (1.) we can express the ratio of two electromotive forces, thus :—

$$\frac{E}{E'} = \frac{\tan a^\circ}{\tan a'^\circ} \cdot \frac{f + g + w}{f' + g + w'} \quad \ldots \quad (5)$$

* It is even more accurate to find the E.M.F. of a battery of Minotto elements by counting the number of cells in series, than by direct measurement, provided always that the elements are all in proper order.

We will suppose that E' is the electromotive force in terms of which the other E is to be expressed (E' may be the electromotive force of the standard cell, or of any battery chosen for the standard of reference).

Apart from the accuracy of the readings a and a' themselves, it will be seen that the accuracy of the ratio $\frac{E}{E'}$ depends on the correct knowledge of the factor $\frac{f + g + w}{f' + g + w'}$ in which g, w, and w' (wire resistances) may be taken to be known accurately, while f and f', the internal resistances of the two batteries, though also known, are nevertheless to be found by experiment with the instrument itself, and, as they may represent besides highly variable quantities, the exactness with which f and f' are known can by no means be on a par with that of g, w, and w'.

Thus it is a clear *à priori* that the ratio will be found as correctly as the readings will allow of, if f can be neglected against $g + w$, and f' against $g + w'$, since under these conditions only would the errors in f and f' have the least possible effect. It will, therefore, be advisable to take invariably the readings through the thin coil of the tangent galvanometer when comparing electromotive forces, for g will then be about 100, and w' if required can be made about 3000 ohms.

Generally the electromotive force in signal offices will have to be expressed in terms of that of the standard cell, whence it follows that a' becomes measurable with $w' = 0$ ($w' = 1000$ would be still better to employ, considering the influence of the error introduced by f', the resistance of the standard cell; with our particular instrument, however, the deflection with one cell through 1000 becomes too small for trustworthy readings, and therefore cannot be used).

Substituting then $w' = 0$ in formula (5.), we get

$$E = \frac{\tan a^\circ}{\tan a'^\circ} \; \frac{f + g + w}{f' + g} E' \quad \ldots \quad (6)$$

which is the best form, and that mostly to be used in practice.

Example.—*Required the electromotive force of a battery of* 20 *cells, connected up in series, in terms of that of the standard cell.*

f and f', the internal resistances of the battery and standard cell respectively, are known to be

$$f = 380$$
$$f' = 16$$

Then, taking the two readings through the thin coil:—

	+	−	mean	
$a =$	69	70	69·5	deflection with 20 cells and 2000 in circuit
$a' =$	70	70	70	deflection with standard cell and no resistance in circuit

$$E = \frac{2{\cdot}70}{2{\cdot}75} \cdot \frac{100+2000+380}{100+16} \times E'$$
$$= 20{\cdot}99\ E'$$

Or, in case the measurements are sufficiently precise and the purpose for which a determination of E is required demands the greatest possible accuracy of results obtainable, we must substitute the exact values of g and w, namely,

$$\left.\begin{array}{l} w = 1975 \\ g = 103 \end{array}\right\} \text{at } 80^\circ \text{ F.}$$
$$E = 20{\cdot}108\ E'$$

the readings having been taken at 80° Fahr. temperature, corrections for w and g are not required.

It may happen that the two batteries which are to be compared are very nearly equal, either both small (almost

equal to the standard cell) or both very large. In such a case it is clear the two readings must be taken with $w = w'$, *i.e.*, in the first case by making

$$w = w' = 0$$

and in the second by making

$$w = w' = 2000$$

and therefore it is better to have always the general formula in mind, and transform it according to requirements. Examples to illustrate this are not considered necessary.

Hitherto we have always supposed that any two readings introduced into the same formula have been obtained through one and the same coil of the tangent galvanometer. It may, however, happen that it is convenient, nay even necessary, to take the one reading with the thick coil and the other with the thin coil, whence it follows that before being able to introduce the readings into the same formula we must know the value of the readings obtained with the one coil in terms of those obtained with the other coil. Say, for instance, we send a current C through the thick coil and get a deflection a°, while a current C' through the thin coil gives a deflection a'°, then, according to the principle of the tangent galvanometer, we have the following two equations :—

$$C = \frac{H}{K} \tan a^\circ$$

$$C' = \frac{H}{K'} \tan a'^\circ$$

$$\therefore \qquad \frac{K}{K'} = n = \frac{C' \tan a^\circ}{C \tan a'^\circ}$$

which is an absolute number, constant for the same instrument, and may be called most appropriately "the

reduction coefficient of the two galvanometer coils." This coefficient should be determined for each instrument most accurately.*

In the following table are given a few determinations of n that have been made with instrument No. 92.

Instrument.	No. of cells.	C in Oersteds.	Deflections.	C' in Oersteds.	Deflections.	n
No. 92.	1	0·083	57·00°	0·006	54·75°	0·078670
	,,	,,	,,	0·004	45·00°	0·074210
	,,	,,	,,	0·003	36·75°	0·074535
	,,	0·054	45·00°	0·006	54·75°	0·078526
	,,	,,	,,	0·004	45·00°	0·074074
	,,	,,	,,	0·003	36·75°	0·074398
	,,	0·041	37·50°	0·006	54·75°	0·079360
	,,	,,	,,	0·004	45·00°	0·074775
	,,	,,	,,	0·003	36·75°	0·075188
Mean, .	.	.	.	.	.	0·075971

* Henceforth the value of n will be given in the memorandum issued with each instrument. Most of these galvanometers have been manufactured in the Alipore workshops by native mechanics (chiefly Hindoos), and the great regularity of the workmanship, as measured by constancy of the coefficient n, proves the natives of India to be capable of exact mechanical execution.

The following are a few of the numbers obtained with the galvanometer No. 355, made by Messrs. Latimer, Clark, & Muirhead for the Royal Indian Engineering College :—

Instrument.	No. of Cells.	C in Oersteds.	Deflections.	C' in Oersteds.	Deflections.	n
No. 355	1	·069920	64° 5′	·0062961	54° 3′	·13408
	,,	,,	,,	·0045284	45° 0′	·13328
	,,	,,	,,	·0027868	32° 0′	·13126
	,,	·034127	44° 54′	·0062961	54° 3′	·13333
	,,	,,	,,	·0045284	45° 0′	·13223
	,,	,,	,,	·0027868	32° 0′	·13023
	,,	·018416	28° 42′	·0062961	54° 3′	·13575
	,,	,,	,,	·0045284	45° 0′	·13463
	,,	,,	,,	·0027868	32° 0′	·13259
	,,	·013416	21° 54′	·0062961	54° 3′	·13638
	,,	,,	,,	·0045284	45° 0′	·13526
	,,	,,	,,	·0027868	32° 0′	·13321
Mean, .	.	.	.	.	.	·13352
Mean of 48 determinations, .	.	.	.	.	.	·13258

The uniform results obtained for n with one and the same galvanometer prove the accuracy of measurement that can be attained with the instrument in question; and the approximation to equality of n in the different galvanometers proves the sufficiently uniform workmanship of these instruments.

A case where it might be necessary to take the two readings through the two coils of the galvanometer would be, for instance, the measurement of the resistance between two earth-plates. Such a resistance, when the ground is damp and the plates are good, may be often very small, perhaps only the fraction of an ohm, whilst at the same time the difference of potentials between the earth-plates may be sufficiently great, although really small—*e.g.*, the fraction of a volt, to cause a sensible deflection of the needle through either coil, when no external resistance is inserted in the circuit. Now, to employ a second electromotive force in such a case would be, for two reasons, objectionable—it would polarise the plates and cause variation in their potentials and resistances during the measurements, and a testing battery of exceedingly small internal resistance would be requisite, which might not be available. The best method would be to take a reading through each of the coils without inserting any external resistance. Then we have

$$\tan a^\circ = \frac{K}{H}\frac{e}{g+x}$$

through the thick coil, and

$$\tan a'^\circ = \frac{K'}{H}\frac{e}{g'+x}$$

through the thin coil, where e is the electromotive force between the plates.

$$\therefore \quad \frac{\tan a^\circ}{\tan a'^\circ} = \frac{K}{K'}\frac{g'+x}{g+x}$$

$$= n\frac{g'+x}{g+x}$$

Whence

$$x = \frac{n\,g' - \dfrac{\tan a^\circ}{\tan a''^\circ}\,g}{\dfrac{\tan a^\circ}{\tan a'^\circ} - n} \qquad \ldots \qquad \ldots \qquad (7)$$

The determination of the electromotive force e will present no difficulties.

EXAMPLE.—*Required the resistance between a copper earth-plate buried in damp ground and a coil of iron wire sunk in a well.*

First ascertain that the electromotive force between the two bodies is sufficiently great to give readable deflections through both coils with no external resistance in circuit; and then take the following three readings:—

	+	−	mean	
a	= 37	37	37	through thick coil
a'	= 10	10	10	through thin coil
a''	= 72	72	72	standard cell through thin coil

and let $n = 0{\cdot}0743$ be the known reduction coefficient of the coils.

Then substituting in formula (7.), and remembering that

$$\left.\begin{array}{l} g' = 100{\cdot}5 \text{ ohms} \\ g = \quad 1{\cdot}1 \quad ,, \end{array}\right\} \text{at } 75^\circ \text{ F.}$$

we have

$$x = \frac{0{\cdot}074 \times 100{\cdot}5 - 1{\cdot}1 \times \dfrac{0{\cdot}753}{0{\cdot}176}}{\dfrac{0{\cdot}753}{0{\cdot}176} - 0{\cdot}074} \text{ ohm}$$

$$= 0{\cdot}649 \text{ ohm}$$

Further, by means of equation (5.) we deduce the electromotive force e, thus:—

$$\frac{e}{E} = \frac{\tan a''^\circ}{\tan a'^\circ} \times \frac{0{\cdot}649 + 100{\cdot}5}{20 + 100.5}$$

since $w = w' = 0$, and 20 is the known internal resistance of the standard cell.

$$\therefore \qquad e = \frac{0{\cdot}176}{3{\cdot}078} \times \frac{101{\cdot}149}{120{\cdot}5} E'$$
$$= 0{\cdot}048\, E'$$

that is, e is about the twentieth part of a volt.

4. *Application of the tangent galvanometer to receiving signals from the line.*

Of course as any line, even the shortest, offers always a considerable resistance, the signals must be read by receiving the line current through the thin coil. Further, it is obvious that, to have the signals as strongly indicated as possible, no external resistance must be inserted. For reading, therefore, connect the thin coil of the instrument between the rest contact of key and earth wire, and arrange the two small copper stops belonging to the instrument one on each side of the aluminium pointer. If well adjusted, signals can be read which are due to ten cells through 5000 resistance.

§ V. *To Control the Correctness of the Galvanometer Coils, and Resistance Coils in connection with them.*

There would be no need to give additional explanations of how to control the resistances of the different coils of the instrument, if there were a known resistance at hand with which comparison could be made, for in that case the procedure would be identical with that already laid down. But as in most offices the resistance coils in connection with the tangent galvanometer are the only standards available, it is necessary to give some method of controlling the instrument. We shall suppose, therefore, that no other known resistance is available.

1. *Determination of the ratio between the resistances of the two galvanometer coils.*—Select two elements that

give the same deflection through the thick coil of the instrument with no external resistance in circuit, which it will be always possible to do in any office. Thus, whatever may be the resistance of the thick coil, so long as it has kept constant while the two deflections were taken, the two cells must have the same internal resistance, say x; and we may then take the following two readings:—

$$\tan a^\circ = k\frac{E}{g+x}$$

(through the thick coil with the one cell and no external resistance),

$$\tan b^\circ = k\frac{E}{g+\frac{x}{2}}$$

(through the thick coil with the compound cell [the two cells parallel], and no external resistance).

$$\therefore \qquad \frac{\tan a^\circ}{\tan b^\circ} = \frac{g+\frac{x}{2}}{g+x}$$

Putting $\quad \dfrac{\tan a^\circ}{\tan b^\circ} = \dfrac{m}{2}$

$$m = \frac{2g+x}{g+x}$$

whence $\quad \dfrac{x}{g} = y = \dfrac{2-m}{m-1}$

The ratio $\frac{x}{g'} = y'$ for the thin coil could be found in precisely the same way, but it is not required for our purpose. It will be clear that in case of the thick coil x must be selected small,* so that g may not be small in proportion to x; while in the case of the thin coil it

* Not so small, however, as to cause the deflections to exceed the prescribed limit.

will be advisable to select x large, say 30 ohms. Next take two readings with the same cell (resistance x), one through the thick and the other through the thin coil, in both cases without any external resistance in circuit, when we get the following two equations :—

$$\tan a^\circ = k \frac{E}{g + x}$$

$$\tan a^{\circ\prime} = k' \frac{E}{g' + x}$$

$$\therefore \qquad \frac{\tan a^\circ}{\tan a'^\circ} = q = \frac{k}{k'} \frac{g' + x}{g + x}$$

Divide by g, put $\frac{k}{k'} = n$, and for $\frac{x}{g} = y$ its value, when we get

$$\frac{g'}{g} = z = \frac{1}{n\,(m-1)} \{q - n\,(2 - m)\} \qquad \ldots \qquad (8)$$

Now n, the reduction co-efficient of the galvanometer, being independent of the resistances of the coils, we can take it as known; further, m and q having been found by experiment are also known, and z can therefore be calculated. Having thus ascertained z, the ratio between the resistances of the two galvanometer coils, and found that it corresponds sufficiently with the one given in the record of the instrument, we may assume with certainty that the absolute magnitudes of the resistances have not altered, for if they had, they must have done so proportionally, an effect that could only be produced by change of temperature.

2. *Determination of the ratio between the resistances of the galvanometer coil and its corresponding resistance coil.*—Take two readings with the same element (resistance x) through the same coil, one without any external resistance, and the other with the resistance coil to be controlled in circuit.

Then we have the following two equations, say, for instance, with the thick coil :—

$$\tan a^\circ = k \frac{E}{g + x} \text{ (with no external resistance)}$$

$$\tan b^\circ = k \frac{E}{g + x + w} \text{ (with } w \text{ the resistance coil to be controlled)}$$

$$\therefore \qquad \frac{\tan a^\circ}{\tan b^\circ} = m' = \frac{g + x + w}{g + x}$$

divide by g, substitute for $\frac{x}{g} = y$ its value, and develop $\frac{w}{g} = z'$, when we get very simply

$$z' = \frac{m' - 1}{m - 1} \qquad \ldots \qquad \ldots \qquad (9)$$

In the same way the ratio between the other resistance coil and its corresponding galvanometer coil can be ascertained.

Now, again, if this proportion z' correspond with the one that can be calculated from the actual magnitudes given in the memorandum for g and w, we may rest assured that no perceptible alteration in these magnitudes can have possibly taken place. Here it must not be forgotten that as the resistance coil w consists of German silver wire, and is therefore very little affected by the variations of temperature, while g consists of copper wire, and is far more affected by change of temperature, it is clear that, before comparing the measured ratio $\frac{w}{g}$ with the calculated one, a correction for temperature must be made for the latter. For instance, say the temperature at which the controlling tests are made is 100° Fahr., while the resistance of g is given at 80° Fahr., then g must be corrected in the usual way to 100°

Fahr.; the resistance w will not require correction in practice.

The whole will be made clear by an example, taken from actual measurements with an instrument whose $n = 0{\cdot}1057$.

EXAMPLE.—First cell (single) gives

	+	−	mean	
$a =$	52	54	53	through thick coil and no resistance.
$a' =$	58	60	59	through thin coil and no resistance.

Second cell (single) gives

	+	−	mean	
$a =$	51·5	52·5	52	through thick coil and no resistance.

Compound cell (two cells joined parallel) gives

	+	−	mean	
$b =$	67	69	68	through thick coil and no resistance.

Now
$$a = \frac{53 + 52}{2} = 52{\cdot}5$$

$\therefore$
$$m = \frac{2 \tan 52{\cdot}5^\circ}{\tan 68{\cdot}0^\circ} = 1{\cdot}0531$$

Further,
$$q = \frac{\tan 53^\circ}{\tan 59^\circ} = 0{\cdot}7974$$

$$\therefore \frac{g'}{g} = z = \frac{1}{0{\cdot}1057\,(1{\cdot}0531 - 1)}\{0{\cdot}7974 - 0{\cdot}1057\,(2 - 1{\cdot}0531)\}$$
$$= 124{\cdot}239$$

The resistances of the coils given in the memorandum are

$$g = \quad 0{\cdot}95 \text{ ohms}$$
$$g' = 111{\cdot}70 \quad ,,$$

which would make

$$\frac{g'}{g} = z = 117{\cdot}58$$

which agrees within 5·66 per cent. with the experimental determination of z; and we may therefore conclude that no alteration has taken place in the coils.*

Again, by experiment (at 98° Fahr.) we find

	+	−	mean	
$a =$	52	54	53	through thick coil and no resistance.
$b_1 =$	31	32	31·5	through thick coil and "20" resistance.
$b_2 =$	6	6	6	through thick coil and "200" resistance.

Whence we have for the ratios of its two resistance coils to the thick galvanometer coil

$$\frac{\text{“20”}}{g} = z'_1 = 21{\cdot}95$$

and

$$\frac{\text{“200”}}{g} = z'_2 = 218{\cdot}95$$

The marked resistance of g is 0·945 at 80° Fahr., which becomes 0·982 at 98° Fahr., of the "20" coil is 20·13, and of the "200" coil is 199·97, so that, according to the memorandum, the above ratios should be at 98° Fahr.

$$z'_1 = 20{\cdot}58$$
$$z'_2 = 204{\cdot}42$$

which agree within 6·66 and 7·11 per cent. respectively with those found by experiment.†

* [In making these determinations great accuracy is necessary in the measurement of the angles. It will be found by calculation that, in the above example, an error of half a degree in the measurement of the angle a will so influence m as to produce a difference of about 28 per cent. in the final result, whilst the same error in the measurement of b will cause a difference of nearly 100 per cent.—H. M.]

† [In this case also an error of observation will produce considerable influence on the result. In the measurement of b an error of half a degree will make a difference of nearly 4 per cent. in the value of z_1'.—H.M.]

Hence we may conclude that the resistance coils of this instrument are correct.*

§ VI. *Elimination of the Influences of the Natural Currents.*

In this case we must invariably take two readings. The one when natural current and test current are in the same direction, and the other when the test current has the opposite direction to the natural current. Hence we have only to reverse the test current with respect to the natural current. As the circuit is *a single one*, the mean of the two tangents observed will give the correct result.

§ VII. *General Rules.*

Before concluding this chapter, it will be advisable to lay down the general rules for the use of the tangent galvanometer.

1. The officer in charge should make perfectly sure that his tangent galvanometer is in good order, and he should therefore from time to time execute the experiments as laid down in §§ III. and V.

2. The most accurate results are obtained when the readings are taken near 45°; and the nearer together the deflections obtained in the two observations lie, the better.

3. Any resistance greater than 350 ohms is to be measured with the thin coil, and any resistance smaller than 350 ohms with the thick coil. This rule is also applicable in measuring the resistance of batteries of small electromotive force.

4. The practical limits of measurement with the

* Similarly we can determine the ratio of the thin to the "2000" coil.

instrument in question are 0·5 to 5000 ohms, and the electromotive force of the testing battery should vary between 1 and 20 cells about.

5. As a rule, one and the same galvanometer coil is to be used for taking readings to measure the same quantity. An exception to this rule is given at p. 28.

6. The testing battery used for taking the two readings to measure any quantity should be the same. An exception to this rule is given at p. 24, when the resistance to be measured is very high.

7. During transport, the needle is to be taken off the pivot and put in its case.

8. Only when the measurements have been very carefully executed, and it is desired to obtain the result as accurately as the measurements will allow of, need the resistances as given in the memorandum, corrected to the actual temperature at the time of testing, be substituted for the ideal resistances of the galvanometer and resistance coils (*i.e.*, 1, 100, 20, 200, 1000, 2000 ohms).

SECTION I.

BATTERIES.

I. *General requirements of an element.*—Of all the known means of generating the electric current, only that called "galvanic action" has had an extended practical application in telegraphy; and, again, of the numerous galvanic batteries that have been invented since the time of Galvani's and Volta's discoveries, that known as "*Daniell's Element*" * has been mostly used in telegraphy.

* This combination was suggested by Professor J. F. Daniell, of King's College, London, in 1836 (*Philosophical Transactions*, vol.

Any form of battery, to be suitable for the purposes of telegraphy, should fulfil the following conditions:—

Be simple in construction; easily prepared; easily maintained in good order; sufficiently intense; approximately constant; tolerably free from local action; so far as first outlay is concerned, inexpensive; and consist of materials readily procurable.*

To find an element fulfilling all these conditions perfectly would be difficult, and is scarcely to be expected; but an experience of more than ten years in India has proved that Minotto's form of Daniell's element practically meets very fairly the above requirements,† and is well adapted to the country.

In Appendix IV. an outline of the theory of Daniell's element is given.

II. *Description of Minotto's element.*‡—At the bottom

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lxxix. p. 107). Since then many modifications, with the object of securing certain practical and theoretical advantages, have been made; of these may be mentioned Kramer's, Meidinger's, Siemens' and Halske's, Minotto's, &c. See Sabine, p. 221.

* The *intensity* of an element is measured by the *maximum* current it can produce, *i.e.*, when on short circuit; it is directly proportional to its electromotive force, and inversely proportional to its resistance.

† It had been taken for granted that the local action of a Minotto element, *i.e.*, its consumption of material when not closed, was very small; this, however, it has been found lately, does not seem actually to be the case. A careful investigation of the probable maximum amount of sulphate of copper that should be consumed annually by the working currents as used in India (these currents are known in probable magnitude and variation) has shown that actually much more than twice the quantity of sulphate of copper is used than can be explained by the currents; and, though the cost of battery material will be always a very small item when compared with all the other expenses a large telegraph administration has to incur, if the waste be really due to local action in the cells, it will be nevertheless of sufficient importance to endeavour to remedy it in the course of time, as so great a waste arising simply from imperfection cannot be allowed to go on for ever.

‡ Signor Minotto, of Turin, is the inventor of this most practical form of Daniell's cell. It was introduced into India in 1868, and at

of a jar, which may consist of any durable and insulating material, such as porcelain, earthenware, gutta-percha, glass, &c., is placed a copper disc, to which is attached an insulated copper wire which passes up through the cell. On the copper disc are placed small crystals, or, still better, fine powder of sulphate of copper. Above these the diaphragm is formed by a layer of sand or sawdust, on which the zinc disc rests. Sufficient water is poured in to just cover the zinc disc. The internal resistance of the cell decreases with the thickness of the diaphragm interposed between the two discs; and thus, as the diaphragm may be made of any thickness, this form of cell is well adapted for readily obtaining any desired internal resistance. The cell, if properly looked after, remains active till the sulphate of copper is entirely consumed.

The electromotive force of a Minotto's cell, which is about *one* volt, is a very constant quantity, and it either exists to its full amount or it does not exist at all—there are no intermediate conditions. As the Minotto cell is so well known, it is not considered necessary to give a drawing of it here. The dimensions of the cell actually in use in India are:—

	Inches.
The outside diameter of jar, . . .	5·25
„ inside „ „ . . .	4·75
„ thickness of earthenware, . . .	0·25

the end of 1869 every station in India had been supplied with it. The great practical advantage of Minotto's element is that it does not contain the usual porous cell as a diaphragm (which it is difficult to procure, especially here in India, and which is liable to break and to lose its porous character), but contains in lieu of it sawdust or sand (at least one of which can be always procured easily and cheaply in any part of India). A cell introduced by Siemens and Halske is almost the same. The diaphragm consists of paper pulp, and later a tube was added for feeding the cell. Sir W. Thomson introduced a similar form of Daniell's element to that called Minotto's in 1858 for working the Atlantic cable.

	Inches.
The height inside, ...	5·00
„ diameter of zinc disc, . . .	4·00
„ thickness of zinc disc, . . .	0·50
„ height of zinc neck, including brass screw,	3·00
„ thickness of zinc neck at base, . .	0·60
„ diameter of copper disc, . . .	4·50
„ thickness of copper disc, . . .	0·04
„ diameter of copper wire, . . .	0·07
„ „ of wire covering, . . .	0·25

In India, round jars, made of glazed and highly-vitrified stoneware, are employed. The sulphate of copper will find its way out of any but the best material. To secure a better insulation, the jar stands on three conical feet.

III. *Preparation of the cell.*—The jar must be sound and perfectly clean, if the earthenware be at all porous the sulphate of copper will crystallise out through it; the copper disc must be free from oxide and grease; and the sand or sawdust free from all foreign matter (the dust of some hard wood should be employed, teak by preference, and it should be well washed and cleaned before use). The insulated copper wire, to be attached to the copper disc, must be sufficiently long to allow the cells to stand at least half an inch apart, and to admit of the descent of the zinc disc in the cells as the sulphate of copper is consumed beneath. This, with the common jars in use, gives a minimum length of 15 inches for the insulated copper wire. The insulating material of these wires must be carefully examined before use, and all those having cracked or otherwise defective coverings must be rejected.

The zinc disc and its binding screw must be clean, and the screw should fit well and bite tightly. See Fig. 2.

The insulating covering of the wire is to be removed from the one end for about $2\frac{1}{2}$ inches, and from the other end for about 1 inch. The $2\frac{1}{2}$ inches of bare copper wire are to be then cleaned and slipped through the three holes in the copper disc, care being taken that the wire is pushed far enough through to bring the insulating covering down into contact with the copper disc. See Fig. 2.

Then the end of the wire threaded into the copper

Fig. 2.

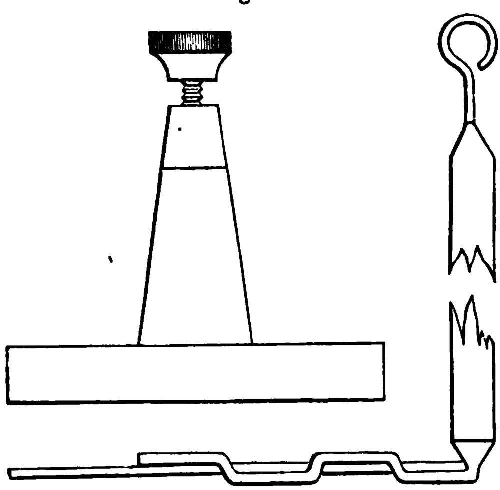

plate must be well hammered to secure a perfect contact between the copper disc and the wire. Soldering the wire to the copper plate is strictly prohibited. Further, the other (1 inch) end of the wire must be also cleaned, and then neatly turned with a pair of pliers into an eye to fit the binding screw of the zinc disc. See Fig. 2.

Generally the insulating covering of the wire, especially if of india-rubber, by no means fits closely to the copper wire, and thus a small empty space between the covering and the copper wire is left, which, in virtue of

capillarity, transports solution of sulphate of copper from the bottom of one cell in the battery up to the zinc of the next. To prevent this most injurious action, it is best to seal both ends up by applying paraffin, shellac, gutta-percha, Chatterton's compound, or sealing-wax. The indiarubber-covered wires now used for battery connections are wound with tape; and to prevent the ascent of the liquid by spreading along the tape, these wires should be soaked in melted wax.

After the sulphate of copper has been placed on the copper disc, to prevent the mixing of the sand or sawdust with the sulphate, a disc of blotting paper or coarse calico should be placed on the top of the sulphate of copper. The sawdust must not be too wet. It is obtained in the best condition by taking handful after handful out of the soaking vessel, each time carefully pressing out the water. The first few layers of sawdust should be gently pressed, but those above, and particularly round about the insulated wire (in order to keep it fixed in its place), must be firmly rammed down. The jar should be filled to within about two inches of the rim, and the surface made perfectly level and smooth. One of the reasons why sawdust is better than sand is, that the latter is *not* compressible, while sawdust is, and therefore, when sand is used, it is quite impossible to fix the wire along the inside of the jar tightly, and consequently the slightest movement of the wire outside (which may frequently occur when connecting the cells to form different batteries, &c.) will move the wire inside the cell also, which brings the sulphate of copper up to the zinc, and spoils the cell.

A piece of coarse calico or blotting-paper should also be placed between the zinc and sawdust or sand. However, care must be taken that the material interposed between the zinc and the sawdust, and between the saw-

dust and the sulphate of copper, does not offer any perceptible resistance. Paper, for instance, which contains much lime should not be used, but good blotting-paper will always answer the purpose well. If a cell is to be employed for line purposes, it must be charged with twelve ounces of sulphate of copper, if for local purposes with twenty-four ounces.

After the cells required for a certain battery have been prepared in the manner stated, arrange them if possible on the stand in the very way they will have to be used afterwards, to prevent the necessity of moving them when in working order. To bring the cells into working order, each cell is to be short-circuited by simply joining the copper wire to the binding screw of the zinc disc.* Then water is to be added until it stands permanently at about one-eighth of an inch above the zinc discs. The electromotive force of the cell is established to its full extent † so soon as the water has penetrated to the sulphate of copper, while the resistance at the beginning is naturally very high. However, the slight current passing through the short-circuited cell has the tendency to reduce the internal

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* To short-circuit each cell separately is better than joining all the cells up either parallel or in series. For, if the cells are all joined up in series, the existence of one cell of abnormally great resistance will indefinitely delay all the cells in coming into working order; and, if they are all joined parallel, there will be excessive action in the cells of lower resistance, which will act as shunts to the cells of great resistance, and the former will come quickly into working order, while the resistances of the latter will scarcely be diminished. The three methods could only be equally good if all the cells behaved identically. However, when there is no hurry to bring the battery into order, it is best to connect all the cells up in series.

† This has been ascertained from many exact experiments by measuring the electromotive force with a condenser, when the internal resistance has no influence. If, therefore, a cell in which the water has penetrated to the sulphate of copper does not give any current on the ordinary instruments, it must be attributed to high resistance of the cell, but not to imperfect electromotive force.

resistance gradually until it has become so low that the cell may be used for actual work. Thus it follows that at the beginning a small quantity of the battery material in each cell is consumed to bring the cell into working order. This way, however, is considered the cheapest and safest. The addition of dilute sulphuric acid to accelerate the action is not permitted.

In order to waste as little battery material as possible, by keeping it short-circuited longer than is necessary, each cell should be tested from time to time to ascertain its progress until it fulfils the conditions to be laid down hereafter. Further, as for local cells, the maximum internal resistance allowed must necessarily be lower than the maximum resistance allowed for line cells ; it is economical to use cells, destined for local work, in line batteries so soon as their resistance has been reduced to the high maximum allowed for line cells.

In joining up the cells when ready for actual use, care must be taken to attach the copper wires to the binding screws of the zincs with the run of the eye directed so that the turning *down* of the screw tends to close the eye, and not to open it, *i.e.*, with the run of the eye *from* left *to* right. In fact this precaution must always be observed in attaching wires to binding screws. This may appear to be a very small point, but it is nevertheless of very great practical importance to secure good and safe contacts.

As a general rule, the cells, when once ready, should be moved about as little as possible, and always with the greatest care, to prevent the mixing of the two liquids. In line batteries the cells must always be connected in *series*, as even the shortest lines in this country are so long that no benefit would be derived from any other arrangement. In the case of local batteries, the manner of joining up the cells will entirely depend on

the resistances and number of the sounders to be worked, as will be seen from rules given hereafter. It may happen that some of the cells will not come into working order. This is invariably due to the presence of air, that has been unable to escape, between the crystals of sulphate of copper. In this case piercing the sawdust with a needle (best of hard wood) will remedy the defect. Further, even if a cell be in perfect order, but closed through a very small resistance (as in the case of local batteries), and therefore generating a very strong current, the free hydrogen at the copper disc may not be all taken up, or the excess be able to escape through the diaphragm quickly enough, and therefore may accumulate to such an extent as to make the resistance of the cell almost infinite. Here the same remedy may be applied, and from this fact it follows that it is advisable not to pack the sawdust too tight, especially in local cells.*

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* REMARK.—To decrease the local action and, further, also to increase somewhat the electromotive force of a Daniell (Minotto), the zincs are often amalgamated. This is, however, a rather expensive expedient, and a large Department could scarcely afford to adopt it generally, especially as the advantages derived from it are very small, and some of them even problematical. Besides, in a Minotto cell which is started with pure water there will be scarcely any free sulphuric acid left by the working current to attack the zinc when no current passes or the circuit is open; thus the local action for this reason may be considered as nil. Any sulphuric acid produced by the low action of the feeble line currents will be almost immediately taken up by the zinc to form sulphate of zinc, which behaves neutral to zinc. Another reason that has been advanced for the amalgamation of zincs is to eliminate the local action that must set in so long as the zinc is impure, and not homogeneous. However, my own experience goes to show that this is by no means an established fact, but that amalgamated zincs are eaten away quicker than those not amalgamated, even when cast from the same block. The increase of electromotive force by amalgamating the zinc cannot be doubted, but it is so small that the same increase can be much more cheaply effected by adding a few cells with unamalgamated zincs. Hence the amalgamation of zincs is prohibited.

IV. *Maintenance of a battery.*—The water must be kept at a level of about one quarter of an inch above the zincs. Water, therefore, will have to be added frequently—every day during the dry season, and this is best doneby means of a small syringe.* Great danger is incurred by adding an excess of water, as it may enter the joint between the neck of the zinc disc and the brass binding screw, cause galvanic action to ensue, and a consequent solution of the zinc, forming sulphate of zinc. The sulphate of zinc when dry is a very bad conductor, and would offer a very great resistance,† and perhaps interrupt work. This must be guarded against by constant attention to the amount of water added. When this fault is suspected, a conductivity test should be taken between the binding screw and disc. When the zinc in a 12-ounce cell has sunk 1 inch below its original position, or in a 24-ounce cell 2 inches, the cell, although no falling off of the electromotive force may have been detected, must notwithstanding be replaced by a fresh one, as it may at any moment become exhausted and cease to function. All cells generate a kind of froth on the surface of the water. This must be fre-

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* This syringe must be employed solely for this purpose: a separate one must be provided for removing the old water.

† Two cases of this kind which have come to notice happened in the Jubbulpore office, when one zinc offered a resistance of about 200 and the other 10,000 ohms. These zincs were cut open, and it was found that the zinc surface inside was covered in both cases with dry sulphate of zinc. Since then the necks of the zincs have been cast considerably longer; and further, to prevent the water entering between the zinc and the brass stud, the joint is closed with sealing wax. As it might also happen that zincs may be cast defective in this respect, about 5 per cent. of all manufactured at the Telegraph workshops are tested, but *one* has never yet been found defective, from which it follows that if ordinary care be only taken, the casting of zincs is quite safe in any of the out-stations; and further, that if zincs offer resistance, it is due to the fact mentioned above, against which officers may guard themselves.

quently removed with a wooden spoon or a brush. Any zinc which assumes a dirty black appearance must be at once replaced by a clean one. Should the new zinc also rapidly acquire the same appearance, it shows that the cell is defective, and that the copper solution has traversed the diaphragm. Such a cell must be immediately removed from the battery and broken up. Care must be taken, when adding water, not to spill any on the outside of the jars or battery stand. The best vessel to employ for watering is an engineer's oil-can or an India-rubber syringe. Clean *soft*, and not *hard*, water should be used. The water must not be allowed to become supersaturated with salt. The water should be replaced at least once a fortnight. A sponge may best be used for removing the old water. The amount of deposit on the zincs must not be allowed to become excessive. If the zincs are wiped every time the water is changed, it will tend greatly towards keeping the battery in order. Should the zincs become very dirty, or when the tests show it to be necessary, the zincs must be removed and cleaned. This should be done at once, when they are still wet. If the cleaning has to be deferred, the zincs should be washed for some time before attempting to clean them. When washing the zincs, care must be taken that only the discs and lower part of the necks are under water, and that no water is allowed to get into the joint between the zincs and their brass binding screws. The zincs should therefore be washed in a shallow vessel. The best way of cleaning zincs is by rubbing them with sandstone. In this manner one man is able to clean about five zincs per hour. To have perfect connections between cell and cell, the binding screws of the zincs and the coils of the wires must be kept metallic. This is best done by scraping with a knife. None of these scrapings must be allowed to fall

on to the zincs. To keep the battery well insulated, the jars must not touch each other, and must be clean. Wipe the jars, and especially their rims, with an oil rag. Further, the battery stand should be kept clean and dry. It should be made of well-seasoned hard wood, and neither painted nor varnished. Saturate the wood with kerosene oil. If the shelves become dirty, remove the cells one by one without shaking. To prevent leakage, the battery stands may also be supported by porcelain insulators.

V. *Dismantling of exhausted batteries.*—Any sulphate of copper remaining in the cell should be collected, washed, and reserved for future use. The old sawdust or sand must never be used a second time.

The pure metallic copper which will be found deposited on the copper disc* and in the sawdust must be collected.† The copper discs, having been if necessary cleaned, are

* The pure copper adheres fast to the copper plate, and its removal is therefore difficult, if not altogether impossible. Hence it is proposed to use in future lead discs, from which the copper deposited can be easily scaled off. The use of lead instead of copper is better, for the following reasons:—

The electrical action of lead is the same as copper, since as soon as lead is immersed in sulphate of copper it becomes covered with pure copper, and therefore acts as a copper plate.

Lead, for the same weight, is far cheaper than copper, especially if the plates are cast from pig lead, which can be done.

The copper deposited on the lead can be easily collected without destroying the lead plate. Thus the lead plate may be used for an indefinite period, and the copper can be collected. The value of the pure copper annually deposited by the working currents is more than Rs. 1000. Further, copper plates, if often used, become brittle, get holes, and have therefore a very limited usefulness with respect to time.

† The criterion of a good cell is its having become exhausted without the slightest deposit of copper in the diaphragm, all the pure copper being attached to the copper disc.

If cells are found to be exhausted in this way two facts are proved:—

1. They have been prepared carefully.
2. They have not been carelessly moved about.

available for use again. These discs rapidly oxidise if exposed to the air. They are best cleaned with the juice of the tamarind.* The insulated wire, too, if found perfect in insulation after a careful ocular inspection, may be used again. The tape should be rewaxed. In case, however, the insulating covering should be found defective, it should be taken off and the copper wire kept. The zinc discs, if still sufficiently thick, and not perforated, may also, after having been scraped thoroughly clean, be re-employed. Those which are too much eaten away must be melted up and recast.

VI. *Recasting of zincs.*—Formerly all the zincs required were issued from the Store Branch, most of them being cast at the Calcutta workshops. However, the process of recasting being simple enough, and involving less expense when done in each office (at least in the larger ones), a mould has been issued with which the casting of zincs can be easily managed. The following instructions should be adhered to:—

1. New brass screws, with their studs, can be procured on indent when required.
2. To remove the brass parts of old zincs, break off the necks, and hold the brass part by means of the tongs in molten zinc until all the zinc is melted away from the brass.
3. The old brass studs, with their screws, may be cleaned with tamarind juice, as described above.
4. Zinc should never be melted in a bare iron vessel,

* This is a method of cleaning the surface of metals that the natives of India have used from time immemorial. Tamarinds can be procured cheaply in any bazaar in India. Boil the tamarinds in water, and when boiling immerse the plates until they have a bright appearance; then wash them with fresh water, and leave them under water until they are required for use.

as it would become impure from taking up the oxide of iron. The inside of the vessel should always be luted with clay and *gobur*.

5. As it is essential to have the zinc discs as pure as possible, to avoid local action when they are in use, great care should be taken to clean the old zincs thoroughly before they are recast. Further, as the most of the impure metals in zinc are heavier than zinc, it is advisable to cast fresh zincs from a large quantity of molten zinc, and not to use the dross left in the vessel.
6. Before commencing to cast zincs, the iron mould must be slightly heated until a blue tinge appears on the bright parts.
7. The brass screw studs, especially the part that the zinc is cast on to, should be cleaned, and afterwards heated, to secure their thorough dryness, but not so hot that they cannot be held in the hand.
8. Place the brass stud (without its screw) in its receptacle in the mould.
9. Fasten the pieces of the mould together, and place it on the side which does not contain the hole into which the zinc is to be poured.
10. Hold the mould by means of the tongs and pour in the zinc, care being taken that none of the scum which is on the surface of the molten zinc enters the mould.
11. The zinc should remain in the mould at least three minutes, otherwise the zinc is still soft and the disc is apt to bulge in the centre.
12. Unfasten the pieces of the mould, and remove the zinc disc.
13. After the cast has been approved of, coat the neck up to a point above its junction with the brass

stud with coal tar mixed with resin, or with sealing-wax. This should be neatly applied, and none of the stuff put on that part of the brass piece where the contact is made.

14. As the pieces of the mould are apt to rust when not in use, they must be occasionally opened, cleaned, and oiled.

VII. *Classification of batteries.*—The batteries in use in any office may be classified as follows:—

1. Standard cells.
2. Testing-batteries.
3. Line batteries.
4. Local batteries.
5. Reserve batteries.
6. Portable batteries.

1. *The standard cell.*—This is an element which has been so carefully prepared and handled, and the tests of which have been so satisfactory, as to justify us in considering it a fair representative of the Minotto cell so far as electromotive force is concerned. Its electromotive force is taken as the standard of electromotive force, and by it the efficiency of batteries is gauged. In the same way as the *ohm* is taken as the unit of resistance, so is the electromotive force of the standard cell * taken as the unit in terms of which to express the electromotive force of batteries, or of any other cause capable of producing an electrical current. † After a cell has been

* The absolute unit of electromotive force is the *volt*, which is equal to 0·9268 times the electromotive force of a Daniell's element. Minotto, or our practical unit of electromotive force, equals 1·079 volts.

† When measuring the "natural currents" in telegraph lines, we have a case where a certain cause which produces an electrical current is to be expressed in terms of the electromotive force of the standard cell. Another application will be when determining the E. M. F. between two earth-plates.

selected as a standard, it must be kept very clean and quite undisturbed. The zinc should be changed whenever its surface appears in the slightest to lose its metallic character. The cell must be kept with the circuit open, and be employed for no kind of work other than testing. A cell having about 20 units internal resistance is best adapted for a standard; and, further, it should give a deflection of not less than 60° through the thin coil of the tangent galvanometer with no external resistance in circuit. A small wooden box with suitable connection screws is supplied, in which the standard cell is kept. The box should be screwed on to a table in the signal room.

2. *Testing-batteries.*—These are only required in offices where line testing has been established. The testing-battery in such offices should consist of not less than 30 elements connected up in series. It is essential for the success of testing, and accuracy of results obtained, that the testing-battery should be perfectly insulated from the ground, and that the cells should be insulated from one another.

The insulation of the battery from the ground is best done by Prussian insulators placed under the wooden feet of the battery stand, the stalks of the insulators being fitted into blocks of wood. These insulators should be wiped clean before testing.

To lessen the chance of shunts between the cells and through the wood of the stand, it is best to paraffin the rims of the jars, and for the other preventions see paragraph IV.

If in any office that is not a testing station, a testing-battery should be required, temporary arrangements can always be made to supply a sufficient number of cells for the purpose of testing. It is not advisable to have the resistance of a testing-battery higher than

20 ohms per cell; nor is it advisable to have it much lower.

3. *Line batteries.*—No cell should be used for line work that has a greater resistance than 30 ohms.

The number of cells to be employed depends on the length and gauges of the line to be worked direct; and the following is the rule that is to be adhered to:—

Use for every hundred miles of

	B. W.G.		I. W.G.			
No.	1	=	50	*wire*	4	*cells*
„	3	=	36	„	5	„
„	4	=	30	„	6	„
„	5½	=	24	„	8	„
„	8	=	16	„	12	„
„	9½	=	12	„	16	„
„	12½	=	6	„	32	„

during the dry season; and during the wet season so many more cells as the state of the line may require.

More than 50 per cent. extra will not generally be required. By the length of the line is to be understood the distance to the farthest station with which the office usually works direct, *i.e.*, without translation. No line battery, no matter how short the line, should consist of less than four cells.

Each cell should be given a name by which it is to be recognised in the test records. The most convenient plan is to call the cell, the copper* of which is connected with the line, No. 1, the next No. 2, and so on. As a general rule, it is not requisite to have the line batteries insulated by special means from the ground. Exceptions are only to be made in offices situated in the marine districts, where it is advisable to insulate *all* the line batteries; as also in large offices where the number

* It is best to connect the positive pole of a battery to line, since then the defective insulation of the line has less effect.

of cells used for one line may exceed 50. Here, too, it may be found beneficial to paraffin the rims of the jars.

In many of the intermediate offices between two large stations, line batteries are kept which have to work only occasionally in T. or S., in case the two end stations cannot work direct, and the intermediate office is therefore called in. From all such batteries, when not actually at work, the zincs should be removed, to prevent the consumption of battery material by local action. However, notwithstanding this, the water should be kept at the regulation level, and the zincs near the battery, so that no delay may occur when they are required.

The number of line cells in use throughout India, British Burmah, and Ceylon during the year 1872–73 was 7897 during the dry season, and 10,375 during the wet season.

4. *Local batteries.*—No cell should be used for local batteries that has a resistance of more than 10 ohms. Local batteries are employed for working armatures, the electromagnets of which are coiled with thick wire, and have consequently a low resistance, as, for instance, the sounders of the common receiving instruments, the electromagnet of an inkwriter, the coils of an alarum as used with the calling-in-arrangement, &c. The manner of connecting up the local cells depends entirely on the purpose for which they are required, and therefore no general rule can be laid down, but each special case that requires notice will be treated of hereafter.

If a certain number of local cells be given, there are always a certain number of ways in which they can be connected up so as to form batteries of different electromotive forces and different resistances. Of all the ways possible we consider, however, in practice only those

which give such an electromotive force that each element in the battery has the same surface.

For instance, say that 8 local cells are given, each with an internal resistance equal to f, the electromotive force being assumed to be constant. Then we have 4 different ways of connecting up the 8 cells as given in the following table:—

Manner of connecting up.	Total electromotive force of battery.	Total resistance of battery.	Surface of a compound cell.	Resistance of a compound cell.
All in series .	8	$8f$	1	f
Series of 4 .	4	$2f$	2	$\frac{f}{2}$
Series of 2 .	2	$\frac{f}{2}$	4	$\frac{f}{4}$
All parallel .	1	$\frac{f}{8}$	8	$\frac{f}{8}$

An element which consists of several *single* cells with all their coppers and all their zincs joined together, so as to form one large element, is called a *compound* cell. Thus if the following order be given: *Connect up* 20 *single cells to form a local battery with the electromotive force* 4—it will be clearly understood what is meant by it, namely, to join *all* the zincs and all the coppers of any 5 single cells together, to get compound cells each of five times the surface of a single cell, and to connect these 4 compound cells up in series. As local batteries have generally to work through small resistances, and as the current required must be strong, it is clear *à priori* that great care must be taken to eliminate from local circuits all sources that might introduce foreign resistance.

Further, as the consumption of battery material is

proportional to the strength of the currents* passing through the cells, and as this current in a local circuit is generally very large, the quantity of sulphate of copper put in local cells has been increased. Thus, instead of using only 12 ounces as for line cells, 24 ounces are used for local cells.†

During the year 1872–73, 2044 local cells were in use throughout India, British Burmah, and Ceylon.

Here also we adopt the same *nomenclature of local cells* as given for line cells, *i.e.*, the cell, single or compound, the copper of which forms the one pole of the battery, is called No. 1, the next cell No. 2, and so on.

Further, the single cells of which a compound cell consists may be designated by $1_a\ 1_b \ldots\ldots 1_n$ when belonging to the compound cell No. 1, and so on.

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* The quantity of pure metal reduced from a solution of any of its salts in t seconds is expressed by the following formula:—

$$g = 0{\cdot}000158\ a \frac{E}{w} t \text{ grains}$$

where E = the electromotive force in volts which produces a permanent current during t seconds through a resistance equal w ohms.

a = equivalent weight of the metal reduced from its solution, *i.e.*, the weight of the metal equivalent to the part of hydrogen.

Applying this formula in our special case, *i.e.*, the weight of *copper* reduced in one second by an electromotive force = 1 Daniell acting through a total resistance = 1 ohm, we have to substitute

$$\begin{aligned} E &= 1{\cdot}079 \\ a &= 31{\cdot}70 \\ w &= 1 \\ t &= 1 \\ \therefore\quad g &= 0{\cdot}0054128 \text{ grain per second.} \end{aligned}$$

† The average current which passes through a line cell in India = $\frac{1}{157}$ Oersted during the dry season (eight months); and $\frac{1}{79}$ Oersted during the rains (four months); and through a local cell for working a sounder = $\frac{1}{15}$ Oersted. It would then be rational to charge a local cell with nine times as much sulphate of copper as a line cell, when in each office they should become exhausted in about the same time.

Battery stands are now made wide enough to hold four cells cross-ways, because all the sounders issued require four cells in series to work them. By fitting a connecting strap for local batteries along each side of the stand, one shelf will contain thirty-six elements, sufficient to work nine sounders if required.

5. *Reserve batteries.*—These are kept in working order, but without zincs in them, to meet any emergency; and, though the number required in any office will depend much on the importance of the office, it is nevertheless certain that the number of reserve cells should not be less than 50 per cent. of the actual number at work during the dry season. From our experience 50 per cent. increase in line batteries during the monsoon is required almost everywhere except in Upper Sindh, where even during the monsoon the climate is so dry as not to affect the insulation of the lines perceptibly.

6. *Portable battery.*—This useful and convenient little battery was introduced in 1867. It is a one liquid sand battery in which the active agent is chloride of ammonium (common sal-ammoniac), which is sold in nearly all the bazaars of India under the name of *nowsada.* It is contained in a small mahogany box (about 11″ × 3″ × 3″) divided into fourteen cells by the plates themselves, so that one side of each cell presents a surface of copper and the other side a surface of zinc, the plates in contact being soldered together. To prepare it, fill the cells to within half an inch of the top with dry fine sand * (or sawdust), and then take it out and mix with it from $\frac{1}{2}$ ounce to 2 ounces of finely powdered sal-ammoniac (according to the time the battery will be

* Pieces of old cotton cloth answer perhaps best. Soak the pieces in saturated solution of sal-ammoniac; then wring out the excess of liquid, and pack the cloth tightly into the cells.

required to remain in action). Place this mixture in the battery and damp it with water (taking care not to put so much in as to leave any standing above the sand), when the battery will be ready for use. It is true that this battery is very inconstant in virtue of polarisation; if, however, it be used only through a considerable resistance, as is the case when signalling through a line, it remains sufficiently constant for short periods. When first prepared it has a resistance of about 200 ohms, and an E. M. F. of from 10 to 12 volts. It is at once in working order, and should *never* be *short-circuited*, which would destroy its electromotive force.*

As the electrical action is maintained by the solution of the zinc plates, which also goes on when the battery is not closed, it is necessary, in order to prevent undue waste, that, immediately the cause for using the battery has ceased, all the sand and sal-ammoniac be taken out, and the whole box immersed in clean water and allowed to remain so for a short time. Then, after well brushing the inside and hinges of the box, the whole is to be wiped and dried in the sun. The occasional use of a little oil will preserve the mahogany and the hinges.

VIII. *Battery testing.*—For the recording of battery tests, see Appendix V. The measurement of the electromotive forces and resistance of batteries has already been treated of in describing the tangent galvanometer. It only now remains to state the general and special rules under which the battery testing has to be conducted in Telegraph offices. From the beginning it must be clearly understood that the object of testing batteries is to *ascer-*

* To prevent any chance of local action at the upper edges of the plates, their rims should always be coated for about ¼ inch with a mixture of pitch and asphalt, or some similar composition.

tain and *maintain* their normal condition.* To this primary object must, however, be added another, which, though secondary, is none the less important. The results of battery tests, regularly and carefully made, and clearly and fully recorded, will afford that supply of exact information that is requisite to judge of the efficiency of any kind of battery for telegraphic purposes, and that could not well be obtained in any other way, either by direct experiment or by *à priori* reasoning. Thus means of improvement may suggest themselves, it may be in efficiency, in simplicity, in economy, or in all of these.

The condition of any battery is determined by its state with respect to two qualities both susceptible of accurate measurement, *i.e.*, *electromotive force* and *electrical resistance.* The condition of any battery is to be pronounced *normal,* if its electromotive force in terms of that of the standard cell approximates closely to the number of cells that are connected up in series; and if no cell in the battery has a resistance higher than the maximum allowed, from which it follows that the average resistance per cell will also be lower than the fixed maximum.†

1. *Line batteries.*—The necessary number of cells fulfilling the required conditions are arranged on the bat-

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* It is strange, but nevertheless true, that the object of testing, simple as it is, and clear as it should be before the mind of any one entrusted with testing, has been so often, and so persistently, neglected that it is impossible here to pass the fact over in silence. Battery testing in many offices has been executed as a mere matter of routine, because it was ordered to be done; and, instead of testing being considered as a means of arriving at practical results, it has been regarded as the work itself, and as entailing no benefits whatsoever. If testing be executed with so little physical spirit and true understanding of its purposes, it would be better to dispense with it altogether.

† The magnitude of the maximum chosen depends on the form and nature of the cell and on the purpose for which the current generated by the battery is to be used.

tery stand and connected up in series. The results of each cell are recorded separately in the battery test-book (see Appendix III.) under the name the cell has been given according to the general rule laid down. The total resistance of the battery is then measured in the battery room, when the result should approximate closely to the total resistance found by adding together the known resistances of the several cells composing the battery. Note, at the same time, the deflection given by the battery through the thick coil of the tangent galvanometer with no external resistance in circuit. Then the current is expressed by

$$c = \frac{n\,e}{n\,f + g}$$

where $n =$ number of cells,

$f =$ average resistance of a single cell,

and $g =$ resistance of the thick coil.

But as g, with any battery consisting of more than ten cells, is scarcely more than $\frac{1}{4}$ per cent. of $n\ f$, we can always neglect g against $n\ f$, when we have approximately

$$c = \frac{e}{f}$$

Therefore the deflection obtained with the whole battery, through the thick coil with no external resistance in circuit, should be about equal to the mean deflection obtained with the several cells composing the battery, through the same coil and no external resistance. If this is the case, we are at once assured that the battery contacts are good, and that no perceptible foreign resistance has been introduced in joining up the cells.

Further, measure in the battery room the total electromotive force of the battery in terms of that of the stan-

dard cell. The number obtained should approximate closely to the number of cells in the battery (since they are all in series). Note, also, the deflection which the battery gives through the thin coil of the galvanometer with the 2000 or, better, 3000 ohms in circuit.

After this repeat the above experiments in the signal room,* when the results should agree with those obtained in the battery room. Knowing, then, the two deflections which the battery gives when in its normal condition, all that will be required for the future is to take daily readings of these two deflections with each battery in the signal room, and to record the results in the form given in Appendix III.

Now the natural and most general tendency of a battery is for the electromotive force to keep constant, while the internal resistance decreases with the time it has been working until it reaches its minimum.† The deflection, therefore, through the thick coil should gradually increase with time, while that through the thin coil should remain constant, or, if not, should have a tendency to rise also, though to a far smaller extent. Hence, so soon as it is observed that the two deflections

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* This should always be done from the line commutator, by connecting one terminal of the tangent galvanometer to the testing bar and the other end direct to earth. Thus by bringing each battery to the testing bar, which is easily done by plugging the commutator in the proper manner, the current, when the key is pressed down, passes through the galvanometer, instead of to the line. All the connections from the battery room to the signal room, and *in* the signal room, are therefore included in this test, and so long as these connections are perfect (*i.e.*, their resistance immeasurably small, as it should be), the two deflections with each battery should be exactly the same in the signal room as in the battery room. Futher, the largest offices in India should scarcely require more than ten minutes to take the readings of all the line batteries.

† The minimum internal resistance of a Minotto is about 5 ohms, which seems to be the resistance of the diaphragm (sawdust) when thoroughly saturated from the one side with sulphate of zinc, and from the other side with sulphate of copper.

do not rise, but on the contrary become smaller, it is clear that there must be something wrong with the battery, either in resistance or electromotive force; and it is then the duty of the tester to discover the defect, and remedy it *at once*. When the battery has been restored to its normal condition, the cause of the defect and the manner of the remedy should be clearly stated in the battery test-book in the column "Remarks" (Appendix V.)

As, however, the electromotive force of any tolerably well-prepared Minotto remains constant until all the sulphate of copper is exhausted, and as further old cells should be removed before having become entirely exhausted, any decrease in deflection will generally be due, *not* to a decrease in E. M. F., but to an increase in resistance. Dirty zincs and contacts, it will be found, are the most frequent causes of an increase of resistance, and the quickest remedy in such cases is to change *all* the zincs at once. However, there may be many other causes to produce a decrease in the two readings, and it is just of these that a most complete record should be kept, to increase our knowledge on the subject, and to prevent if possible their recurrence.

If a special testing-battery be kept, the readings of this battery should also be taken daily, and recorded. Reserve batteries are only to be tested from time to time to see if they are in working order, so that no delay may occur when they are wanted.

2. *Local batteries.*—Here the same rules are to be followed as laid down for line batteries. The best plan of taking the daily readings in the signal room is to cut one of the two leading wires in the signal room (before they branch off to the different sounders that are worked by the same local battery), and interpolate the galvanometer. Then, working each relay by its own line battery

(short-circuit the key by putting the blade of a knife between the front and middle contacts), all the sounders will be worked, and the current flowing through the galvanometer will go through all the connections of the local battery under test, in fact as if the instruments were actually at work, and therefore any irregularity in the local circuit must be indicated by these deflections. However, the deflections obtained in the signal room cannot be so great as the deflections taken in the battery room, but the one can be always easily calculated from the other, if the number and the resistances of the sounders, which the local battery in question works, be known; and it is this deflection (calculated from the deflection taken in the battery room) with which the deflection taken in the signal room should agree.

An example will make this clear.

Example.—A local battery, consisting of 12 single elements, connected up 4 in series to form 4 compound cells, and working 3 sounders, the resistances of which are known, gives the following two deflections in the battery room:—

$a^{\circ} = 70^{\circ}$ through thick coil and no external resistance,
$a^{r\circ} = 20^{\circ}$ through thin coil and "2000" in circuit.

What should be the deflections in the signal room when the two readings are taken through the three sounder coils connected parallel?

The sounders have the following resistances:—

$$\begin{aligned} \text{No. } 1 &= 30{\cdot}8 \\ \text{No. } 2 &= 30{\cdot}1 \\ \text{No. } 3 &= 30{\cdot}0 \\ \text{Average} &= 30{\cdot}3 \\ \therefore \quad \text{Parallel} &= 10{\cdot}1 \text{ approximately.} \end{aligned}$$

Further, the average resistance of a single local cell

of the battery under test $= 9$, and therefore that of a compound cell $= 3$; thus the total resistance of the local battery $= 12$ ohms approximately (this resistance may also be determined by direct measurement).

Thus, calling the deflections in the signal room :—

a° through the thick coil and no external resistance,
a'° through the thin coil and "2000" resistance,

we have the following two equations :—

$$\tan a^\circ \propto \frac{4}{12 + g + 10{\cdot}1}$$

$$\tan a'^\circ \propto \frac{4}{12 + g' + 2000 + 10{\cdot}1}$$

Further, from the two readings in the battery room, we have :—

$$\tan 70^\circ \propto \frac{4}{12 + g}$$

$$\tan 20^\circ \propto \frac{4}{12 + g' + 2000}$$

$$\left.\begin{array}{lr} \text{where} \quad g = & 1 \\ \text{and} \quad g' = & 100 \end{array}\right\} \text{about}$$

$$\therefore \quad \tan a^\circ = \tan 70^\circ \, \frac{13}{23{\cdot}1}$$

$$\text{and } \tan a'^\circ = \tan 20^\circ \, \frac{2112}{2122{\cdot}1}$$

whence it follows that a' will be very nearly 20, while a will be considerably less than 70, in this case $= 57$ about.

Therefore, if no perceptible resistances be introduced by the local contacts, local wires in the signal room, &c., the deflections in the signal room should approximate closely to 20° through the thin coil with "2000" in circuit, and 57° through the thick coil with no external resistance in circuit.

Besides dirty zincs and battery contacts, a possible cause of foreign resistance in the local circuit are the platinum contacts of the relays, which therefore should be cleaned from time to time.

IX. *Some Useful Relations between Current, E. M. F., and Resistance of Batteries and the Resistance of Receiving Instruments.*

1. *The E. M. F. of a battery* is proportional to the square root of its resistance.

If we are given any number n of cells of uniform electromotive force e and resistance f, and we connect them up p in series and q parallel so as to form a battery of electromotive force E and resistance F, then we have

$$E=k\sqrt{F}\,* \qquad \ldots \qquad \ldots \qquad (10)$$

where $k=e\sqrt{\frac{n}{f}}$ a constant.

2. *The best arrangement of a battery.*—Any battery will obviously be arranged to the greatest advantage when the current it produces is a maximum. If we call R the resistance external to the battery, then the current will be a maximum if we make

$$F=R\,\dagger \qquad \ldots \qquad \ldots \qquad (11)$$

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* We have

$$pq=n$$
$$E=pe$$
$$F=\frac{p}{q}f$$

eliminating from these three equations p and q, we get

$$E=e\sqrt{\frac{n}{f}}\sqrt{F}$$

† Employing the same notation as before, we have

$$C=\frac{E}{F+R}$$

but

$$E=k\sqrt{F}$$

$\therefore$

$$c=\frac{k\sqrt{F}}{R+F}$$

which expression has a maximum for $F=R$.

3. *Minimum number of single cells to work a given instrument.*—We will call C the smallest current with which a given instrument of resistance S can be worked with engineering safety, then we have

$$p=\frac{2\,SC}{e} \text{ the number of cells in series.}$$

$$q=\frac{2\,f\,C}{e} \text{ the number of cells connected parallel.}$$

$$\therefore \qquad pq=n=\frac{4\,f\,SC^2}{e^2}\text{*} \quad \ldots \quad \ldots \quad (12)$$

the minimum number of single cells required to work a given instrument with engineering safety.

It will be seen that the application of these formulæ is limited. Because, when S becomes sufficiently large, it will be impossible to fulfil equation (1), as q cannot become fractional. This simply means that under

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* The expression for the current is

$$C=\frac{pe}{\frac{pf}{q}+S}$$

for maximum current we have

$$\frac{pf}{q}=S \quad \ldots \quad \ldots \quad \ldots \quad (1)$$

$$\therefore \qquad C=\frac{pe}{2\,S}$$

or

$$p=\frac{2\,SC}{e}$$

this value of p in (1) substituted we get

$$q=\frac{2\,f\,C}{e} \text{ and therefore}$$

$$pq=n=\frac{4\,f\,SC^2}{e^2}$$

e is expressed in volts, and f and S in ohms, when C is expressed in Webers per second called Oersteds.

such circumstances the required current can only be produced by connecting the cells in single series. It is, however, easy enough to develop the formula in this case :—

We have $$C = \frac{ne}{nf + R + S}$$

$$\therefore \qquad n = \frac{C(R+S)}{e - Cf} \qquad \dots \qquad \dots \qquad (13)$$

when R is the external resistance, S the resistance of the receiving instrument, f the internal resistance of a single element of which e is the E. M. F.; while C, as usual, is expressed in Oersteds, representing the known minimum current by which the receiving instrument in question can be worked with engineering safety.

Example 1.—What will be the minimum number of single Minotto cells, each with 15 ohms resistance, to work a sounder of 30 ohms resistance with the regulation current of $\frac{1}{15}$ Oersted?

Substitute in formula (12)—

$$e = 1 \text{ volt}$$
$$S = 30 \text{ ohms}$$
$$C = \tfrac{1}{15} \text{ Oersted}$$
$$f = 15$$

Thus $$p = 4$$
$$q = 2$$

and therefore $$n = pq = 8$$

Hence we should have to employ 8 cells to form a battery with 4 cells in series, and 2 parallel.

2. A sounder of 500 ohms requires a current of 10 Milli-Oersteds to work it efficiently, how many single Minotto cells of 25 ohms resistance each would be necessary to work this sounder through an external resistance of 250 ohms?

Substitute in formula (13)—

$$e = 1 \text{ volt}$$

$$\left.\begin{array}{l} S = 500 \\ R = 250 \end{array}\right\} \text{ohms}$$

$$f = 25 \text{ ohms}$$

$$C = 0{\cdot}01 \text{ Oersteds}$$

Thus $$n = \frac{0{\cdot}01 \times 750}{1 - 0{\cdot}01 \times 25} = 10 \text{ single cells.}$$

4. *Effect of imperfect insulation in the strength of currents.*—Formula (13) is correct only when there is no loss of current along the resistance R. When dealing, however, with signalling currents, this supposition is scarcely ever fulfilled. In such a case we must calculate the number n of cells required to produce the arriving current of strength C by the following formula :—

$$n = \frac{CW^{*}}{\alpha\beta e - Cf} \quad \ldots \quad \ldots \quad (14)$$

where $\alpha = \sqrt{\frac{J - w}{J}}$, $\beta = \frac{J}{J + S}$, e the electromotive force of a single cell, f the internal resistance of a single cell, S the resistance of the receiving instrument, W the

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* If we call C the arriving current and C_0 the local current, then it can be proved (see Appendix) that for uniform insulation and conduction the following relation holds good :—

$$\frac{C}{C_0} = \sqrt{\frac{J - w}{J}} \times \frac{J}{J + S}$$

but $$C_0 = \frac{ne}{nf + W}$$

$\therefore$ $$C = \frac{ne}{nf + W}\sqrt{\frac{J - w}{J}} \times \frac{J}{J + S}$$

From which n developed, and the substitution α and β made, we have—

$$n = \frac{CW}{\alpha\beta e - Cf}$$

measured absolute circuit resistance, J the measured absolute insulation, w the measured absolute conduction resistance.

Formula (14) may be also expressed—

$$n = C \cdot \frac{il + (l + i)\ (l + S)^*}{ie - Cf\ (i + l + S)} \quad \ldots \quad (15)$$

where i is the absolute corrected insulation, l half of the absolute corrected conduction, and the other terms have the same meaning as before.

Example.—For instance, take the results of the No. 1 Jabalpur-Khundwa line (see Test-sheet annexed to Appendix IV., Sect. I., Part II., Vol. I.), and suppose that we desire to know how many cells of 30 ohms resistance each would be required to work the relay with a current of 4 Milli-Oersteds.

From the tests we know—

$$W = 2985$$
$$J = 7375$$
$$w = 2485$$
$$S = 745$$

further, $f = 30$

$C = 0{\cdot}004$

$\therefore$ $\alpha = 0{\cdot}814$

and $\beta = 0{\cdot}908$

and as Minotto elements are employed, $e = 1$ volt approximately.

Therefore by formula (14) we have—

$$n = \frac{0{\cdot}004 \times 2985}{0{\cdot}814 \times 0{\cdot}908 - 0{\cdot}004 \times 30} = 19{\cdot}3$$

or, say, 19 cells would be required.

* This formula has been developed under the supposition that the whole uniform leakage may be placed as the resultant fault in the middle of the line. No difficulties will be met with in developing this formula. (See Appendix I., Sect. I., Part II., Vol. I.)

If, on the other hand, we calculate n by formula (15) we have to substitute—

$$\left.\begin{array}{l} l = 1302 \\ i = 5656 \end{array}\right\} \text{taken from the test-sheet quoted above.}$$

$$\text{Hence } n = 0{\cdot}004 \times \frac{5656 \times 1302 + (5652 + 1302)\,(1302 + 745)}{5656 - 0{\cdot}004 \times 30\,(5656 + 1302 + 745)}$$

$$= 18{\cdot}3$$

We may therefore say that, practically, the two formulæ give the same result.

X. *General Rules.*—In concluding this section, it will be advisable to state the general rules to be adhered to:—

1. So long as the daily tests of the batteries do not show anything abnormal, no alteration in the batteries is to be made, beyond remedying visible defect.
2. So soon as the two deflections of any battery decrease to such an extent as to render it sure that the variation is beyond the limits of observation errors, steps are to be at once taken to find out the cause, and to restore the battery to its normal condition.
3. The daily readings are to be invariably taken in the signal room in the manner described, and arrangements should be made to be able to execute this daily testing with the greatest possible expedition.
4. Any alteration that is made in any battery should be clearly stated in the test record, together with the reasons for having made it.
5. No cell for line use should have more than 30 ohms internal resistance.

6. No cell used for local purposes should have more than 10 ohms internal resistance.
7. No line battery is to be connected up otherwise than with all the cells in series.
8. The manner of connecting up local batteries depends on circumstances, but as a rule not more than 4 sounders should be worked by the same local battery.
9. The minimum resistance that a Minotto element can attain is never much less than 5 ohms.
10. As the efficiency of batteries is one of the most essential conditions of good working, the testing and recording of results, and the preparation and maintenance of batteries, should invariably be done by the head of an office himself. He should on no account relegate this most important technical duty to any one under him.

SECTION II.

INSTRUMENTS AND CONNECTIONS.

I. *Receiving Instruments.*—The receiving instruments employed in India are *all* based on the *electro-magnetic* principle, *i.e.*, the signalling current is made to act on soft iron, neutral or polarised, through a number of convolutions of highly-conducting copper wire insulated by a covering of silk. The current, so long as it persists in these convolutions, produces an alteration in the original magnetism of the soft iron acted upon, either in strength or sign, or both, and thus a force becomes available which is used to produce the telegraph signals either in a *direct* or *indirect* way. Telegraph instruments actu-

ated by electro-magnetism are in fact those which at the present time are mostly used in practical telegraphy.*

At the beginning of telegraphy, when the lines, constructed to convey the signalling current, were by no means electrically perfect (on account of excessive and variable leakage), and when moreover the batteries used for producing that current were inefficient in strength and constancy, the currents which had to be made use of for producing the signals were naturally variable and weak, and consequently (the more delicate and ingenious improvements in the construction of receiving instruments of the present time being wholly unknown) the signals were also weak and inconstant, and therefore often *unreadable.* Hence, improvements in the construction of

* The electric current being able to produce heat, light, magnetism, induction, chemical and physiological effects, it is clear that *all* these forces, separately or conjointly, may be made use of in the construction of telegraph receiving instruments. Neither heat nor light have had, however, any application as yet in ordinary telegraphy, and, for obvious reasons, will most likely never be made use of. The effect of the electric current on permanent magnets (needle instruments) or on soft iron (electro-magnetic instruments) has been mostly used up to the present time. The effect of induction has also been employed in the construction of telegraph instruments of the most varied forms. To avoid the injurious action of the earth currents on cable signals and to limit the size of the signals, Mr. Varley suggested, for instance, to produce the cable signals by induction currents, *i.e.*, the arriving primary current does not act directly but indirectly on the receiving instrument, by inducing Volta induction currents in a coil of wire. The chemical effect of the current (electro-chemical telegraph), though almost the oldest known, has only found as yet a very limited application. But considering the great rapidity with which chemical action by an electric current seems to take place, combined with a most interesting discovery made by Mr. Edison that a current, even the weakest, when passing through paper, chemically prepared in a certain manner, is able to change the surface of that paper almost instantaneously (the paper becomes quite smooth at the place where the current passes), it seems highly probable that the chemical telegraph, especially when combined with duplex working, may yet play a most important part in telegraphy. The physiological effect of the current, although suggested so long ago as 1839, has for obvious reasons not found any application.

lines, batteries, and receiving instruments, were absolutely requisite before that marvellous invention, the electric telegraph, could become really practically useful. Wheatstone's idea of *automatic translation,* which he suggested and acted upon as early as 1837, must be undoubtedly considered one of the first as well as the most effective and striking improvements made. By it the indistinct and weak signals as originally received from the line by a delicate instrument called a *relay,* were transferred automatically to another much less delicate instrument called the *receiver.* This was done by an application of *local batteries* in the receiving station itself. Thus the strength of the signal became independent of the strength of the received line current.

This division of telegraph labour resulted in a rapid progress of telegraphy, for now the difficulty of the weak and irregular currents could be overcome to a very great extent by constructing the relays as sensitively as possible, provided only that the current was sufficient to ensure *regularity;* while the *receiver*—force being available in the receiving station to any required amount—could be conveniently constructed, entirely independent of sensitiveness, to produce such powerful signals as practice showed were requisite to admit of accurate *reading.* At the present time, though many of the reasons which formerly necessitated the use of *relays* and *receivers* as distinct instruments have been eliminated, it may be said that, as a general rule, this early principle still constitutes the basis on which telegraph instruments are constructed, and in India it is almost universally adhered to except on very short lines. In the following, only the instruments in actual use in India will be described, their principles of action will be explained, and special attention will be given to their best adjustment and maintenance. To this will be

added the methods of testing their working efficiency. All these points, though of the greatest practical importance, are generally not treated of in manuals and schoolbooks on telegraphy, and it will be, therefore, useful and justifiable to devote considerable space to these subjects here.

II. *Definitions.*—Before proceeding to describe the different instruments, it will be advisable to give here a few explanations in the form of definitions. This will save time in future. The *efficiency* of an instrument is determined with reference to the following qualities:—

Conduction.—The resistance between any two points of an instrument, which are designed to be in *perfect contact*, should be *nil.**

Insulation.—The resistance between any two or more points of an instrument, which are designed to be insulated from each other, should be *infinite.*†

Performance.—An instrument must function in accordance with the conditions it has been designed to fulfil, and with that degree of perfection which has been found by experience can be expected of it. The performance of many instruments can be strictly measured by a test which I have called the *Range-Test.* See further on.

* Generally the *smallness* of a resistance is relative, and must be considered with respect to the resistance of the circuit in which the resistance of the contact under examination may at any time be included. Thus, for example, a resistance of *one* ohm is considerable if occurring in a *local* circuit, but it is insignificant in a *line* circuit. In practice, of course, the minimum possible resistance is to be aimed at.

† Here, again, the *greatness* of the resistance is relative. In local circuits, and even in line circuits, we may consider *one* megohm sufficiently great; and this is the limit adopted in practice. In cable-testing the insulation of the keys, shunts, and other apparatus must be much greater than this, perhaps several hundred megohms—in proportion, in fact, as the resistance we have to deal with is greater.

Mechanical execution. — An instrument must be strongly made; it should be accurately fitted, properly polished and lacquered, in fact, it should have the right finish; all the springs must be good and well-tempered, and all the movable parts should move without undue friction; all the screws should turn readily, and hold firmly when screwed home or clamped, &c., &c. To see to all these points, and to be able to form the right opinion, no doubt considerable practice is required.

Range.—The range of an electro-magnetic instrument, in a given state of adjustment and for a constant working speed, is the number expressing the ratio of the strongest to the weakest current with which the instrument will function without readjustment. For instance, if with a sounder we set the armature at a certain distance from the poles of the electro-magnet, allow a certain play to the lever, and give the antagonistic spring a certain tension, we shall have given to the instrument a certain adjustment; and by experiment we can find what is the range of the instrument for this adjustment and for the given signalling speed, by finding what is the strongest and what the weakest current with which the sounder will work. Again, if with a Siemens' relay we give a certain play to the tongue, set the shoes at a certain distance from the tongue, and then turn the micrometer screw so as to put a certain rest force on the tongue, we shall have given a certain adjustment to the instrument; and, as before, we can find the range of the instrument for this adjustment by experiment. It does not follow, of course, that the first adjustment we give the instrument is the best, *i.e.*, that under which the instrument will give the greatest range; but by trying various different adjustments, and seeing what range the instrument gives under each, we can find which is the best adjustment for the particular instrument under

examination. When we have thus examined a number of instruments of the same kind, we shall be able to decide what range may be expected of instruments of that class; and so thus fix upon a *standard*, which the range of all instruments of that class should not fall short of. In this way, the standard range of Siemens' relay, for example, has been fixed at 25, as we shall see hereafter.

By measuring the range of an instrument we test the performance of the instrument in respect of two most important points, namely, absence of undue friction in the movable parts (as otherwise the weak current would be unable to move them), and absence of coercitive force in the electro-magnets (as otherwise they would become polarised, and exhibit residual magnetism under the influence of the strong current).

When measuring the range of an instrument we naturally produce the strong current by putting a battery and the instrument only in circuit; while to obtain the weak current, we generally both reduce the battery power and introduce extra resistance into the circuit.

III. *Instrument-Testing.**—Each instrument before issue, is to be tested for *efficiency* as represented by *Conduction, Insulation, Performance,* and is further closely inspected to discover any *mechanical defect.* The performance of electro-magnetic instruments is, of course, invariably measured by the *Range-Test.* The resistance of coils of wire, used as shunts, resistance coils, or to form electro-magnets, is always to be measured,

* A system of testing and examining instruments and telegraph material at the workshops previous to issue, was introduced at the beginning of 1869, on my first arrival in Calcutta, and since this it has been continually extended, until at the present time it constitutes a special and important branch in connection with the workshops.

and the value to be marked in a conspicuous place (reduced to 80° Fahr., the mean temp. of India).

Inspecting officers have to test the instruments in use, according to the rules laid down, and they have to consider this work as one of their most important duties.

IV. *The Range-Test.*—This test is of such great importance that it is justifiable to treat the question in detail, and attach some examples to make the method of procedure clear.

If we call (c) the weakest current, and (C) the strongest current with which a given electro-magnetic instrument can be worked with engineering safety without altering the given adjustment of the instrument; then, according to definition we have—

$$\text{Range} = \frac{C}{c}*$$

Let r = the resistance of the electro-magnet.

w = the resistance introduced to obtain the weak current (c).

n = the number of cells employed to produce the strong current (C).

m = the number of cells employed to produce the weak current (c).

f = the average resistance of a single cell.

e = the E. M. F. of a single cell.

Then—

$$C = \frac{ne}{nf + r}.$$

$$c = \frac{me}{mf + r + w}.$$

$$v = \text{Range} = \frac{n}{m} \cdot \frac{mf + r + w}{nf + r} \quad \ldots \quad (16)$$

* The range is the ratio of *two forces*, but, using the same electro-magnet, these two forces are proportional to the currents, and therefore we may at once substitute for range the ratio of the two currents.

In future we shall always designate the range of an instrument by the letter v.

Now we require to develop formulæ, which will afford answers to two questions which arise in practice:—

1. Given the ratio $\frac{n}{m}$, how large is w to be made in order to get any required range v?

Developing w from equation (16) we get—

$$w = \left(\frac{mv}{n} - 1\right) r + (v - 1)\, mf \quad \ldots \quad (17)$$

2. Given a resistance w, which is the only one available, what must be the value of $\frac{n}{m}$, in order to get any required range v?

Developing $\frac{n}{m}$ from equation (16) we get—

$$\frac{n}{m} = \frac{vr}{r + w - (v - 1)\, mf} \quad \ldots \quad (18)$$

It will be seen that in both of these formulæ (17 and 18) the number of cells (m), employed to produce the lower limit of the current, is left indeterminate. The proper value to assign to (m) is to be determined by the sensitiveness of the instrument under test; this can only be found by experiment, but will be mentioned hereafter in the case of each particular instrument.

Example 1.—A sounder of 500 ohms resistance has to give a range of 25 with 2 and 20 cells of 15 ohms resistance each, what should be the amount of extra resistance added to get the weak current?

$$\text{Here } w = 1{\cdot}5 \times 500 + 24 \times 2 \times 15.$$
$$= 750 + 720.$$
$$\therefore\ w = 1470 \text{ ohms.}$$

which is the amount of resistance that is to be introduced.

Example 2.—A Siemens' relay of 1000 ohms resistance has to give a range of 20, the only available resistance we can add being that of the thin coil of the Tangent Galvanometer with its 2000 ohms resistance coil, or total 2100 ohms. The weak current being produced with *one* cell of 16 ohms resistance, how many cells of the same resistance should be employed in producing the strong current?

Here
$$n = \frac{20 \times 1 \times 1000}{1000 + 2100 - (20-1)\ 1 \times 16}$$
$$= \frac{20000}{3100 - 304}$$
$$= \frac{20000}{2796}$$
$$= 7 \text{ cells about.}$$

The range of any electro-magnetic instrument is a decreasing function of the signalling speed.—On account of *magnetic inertia* of iron, and on account of *Volta-induction* of wire coils (Para. VI.), the iron cores of any electro-magnet will always *resist* the *reception* of magnetism, and will also always *resist* the *vanishing* of that magnetism after the current has ceased; *i.e.*, a given current will require time to produce a certain amount of magnetism, and after the current has ceased a certain time must also elapse before that amount of magnetism can, even approximately, reduce itself to zero. Hence it may be concluded that the range of an electro-magnetic instrument must necessarily be a decreasing function of the signalling speed. The range has been defined as the ratio of two forces between which the working of the instrument may alter, without any irregularity in the signals being caused. Now, it may be said that it is quite impossible to fulfil this condition. For a *constant* adjustment of the relay means nothing else than a given and *constant* rest-force. Therefore, to overcome this rest-

force by another, the working force, and cause always exactly the same effect, necessarily the same working force would be also required, or no range whatsoever would be admissible. But this would represent *absolute* regularity of signals. In practice considerable margin is allowed, for a signaller can read conveniently and clearly within a certain variation of signals. It is for this *practical* regularity, and not for *absolute* regularity of signals, for which *the range* has been defined, and it is this range we mean which decreases with increasing signalling speed. When instituting experiments of this kind it will be observed that, as the signalling speed increases, the lower limit of the current (c) has to be increased, while the higher limit of the current (C) has to be decreased in order to get regular signals.

Experiment.—A Siemens' relay with 517 ohms resistance was given a certain adjustment, and great care taken that this adjustment did not alter during the whole series. The adjustment was such that, by hand-signalling, the usual way of taking the range, the relay worked well with 1 cell through 600 ohms, and with 10 cells through 0, alternately. The battery consisted of 10 Minottos successively connected, of which any number could be selected by a battery commutator. In the circuit of this battery an ordinary resistance box was introduced, together with a tangent galvanometer to indicate the working currents. The resistance of the tangent galvanometer was 100 ohms. The resistance of the battery before and after the experiments was found to be 80 ohms. The signals were made by a *make and break* apparatus, the *Wippe.** It was driven by

* The *Wippe* is a self-acting commutator capable of interrupting or reversing the currents with great rapidity. Such an instrument was constructed by Dr. Wr. Siemens, in the year 1859, for the special purpose of measuring the signalling speed of cables (Sabine, p. 416).

four Bunsen elements successively connected, and with an ordinary resistance box in circuit, to make it possible to alter the current which drove the *Wippe*, *i.e.*, the speed of signalling. A low resistance galvanoscope (0·5 ohms) was placed in circuit of the Bunsen battery, in order to indicate the current which drove the *Wippe.* By taking occasional readings of the line current through the tangent galvanometer, especially *before* and *after* each experiment, we assured ourselves that the current through the relay had kept constant; and by doing the same with the low resistance galvanoscope we satisfied ourselves that the current which drove the *Wippe* had kept constant, *i.e.*, its speed. The results of these experiments, made on the 20th May 1879, have been put together in the following table:—

No. of Experiment.	Speed. (n) Contacts per min.	Current in Milli-Oersteds.		Range.
		c Low Limit.	C High Limit.	$\frac{C}{c}$
1	53	0·89	14·35	16·1
2	101	1·03	14·35	14·0
3	138	1·14	14·35	12·6
4	313	1·81	14·35	7·9
5	419	1·81	8·36	4·6

It will be seen that the lower limit (c) had to be permanently increased with increase of speed; only in No. 4 experiment the lower limit became constant. The higher limit had to be decreased only in No. 5 experiment. The decrease of the range is clearly shown.

430 contacts per minute is a speed about equal to twenty (*five-letter*) words per minute, the word *Paris* being taken as the unit. Therefore, although a relay

may pass the standard range of *twenty* when tested in the ordinary manner, in practice when receiving at a rate of twenty words per minute, we can scarcely expect a range higher than *four*. Considering that the currents used on the lines in India never exceed 8 Milli-Oersteds, and that a relay of about 500 ohms resistance does not work safely with less than 2 Milli-Oersteds, the range *four* at a speed of twenty words, although small, will nevertheless be sufficient, *i.e.*, actually no adjustment of the relay will be required while the arriving current varies alternately between 2 and 8 Milli-Oersteds.

V. *Electro-Magnets.*—Numerous experiments have been made at various times by different physicists, in order to discover the best size and form of the iron cores of electro-magnets, with reference to two qualities most essential for receiving instruments—*Maximum free magnetism* at the poles, and *quickness of action.*

Maximum free magnetism.—It will be clear that, in practical applications of electro-magnets, it is, in the first place, desirable to get for a given current, which passes through the convolutions of the electro-magnet, the greatest possible force for attracting an armature.

Supposing cylindrical iron cores, placed in a cylindrical bobbin of wire, the usual case in telegraphy, then the force exerted by one pole on the unit of magnetism external to the iron core can be expressed by—

$$F \propto c\, u \sqrt{l\, d}\ ^{*} \quad \ldots \quad \ldots \quad (19)$$

Supposing that the wire covers the total length of the iron core uniformly, and that the current (c) is sufficiently small in proportion to the mass of iron used in

* This is an empirical formula given by J. Dub in his *Electro-Magnetismus*, p. 137. Berlin, 1873.

the core, so as not to bring the produced magnetism near to the limit of saturation. In the above formula c stands for current, u for the number of convolutions, l for half the length of the iron core, and d for the diameter of the core.

Further, if we suppose the bobbin closely fitting the iron core, then the inner diameter of the bobbin will also be d. We will call the outer diameter of the bobbin D, *i.e.*, as measured up to the last layer of wire, and by δ we will designate the diameter of wire filling the bobbin. Then approximately we have—

$$u = \frac{(D-d)\,l}{\delta^2}$$

Hence,
$$F \propto \frac{c}{\delta^2}\,\phi$$

in which
$$\phi = (D-d)\,l\sqrt{l\,d}$$

Therefore when c* and δ are constant the attractive force F is proportional to the function ϕ, which for d has an absolute maximum, if we put—

$$D = 3\,d \qquad \dots \qquad \dots \qquad (20)$$

and this law will be true for any current (c), no matter how weak or how strong, and for any diameter.

If we substitute this value of D, the function ϕ becomes—

$$\phi = 2\,d\,l\sqrt{l\,d} \qquad \dots \qquad \dots \qquad (21)$$

Showing that the free magnetism of the poles permanently and symmetrically increases with the dimensions of the core, *i.e.*, with the mass of iron used. This result

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* When d varies independently while δ is kept constant, the resistance of the bobbin also necessarily alters, and, therefore, in order to keep c constant, we must suppose that E, the E. M. F., alters.

is quite natural, and d and l must therefore be left to be determined by other considerations.

Quick action of the electro-magnet.—A perfect electro-magnet clearly would be one in which the magnetism begins and ceases at the very same time as the current does. Magnetic retardation is against this desirable perfection. All that we can do is to reduce this effect to a minimum, by selecting, in the first instance, suitable iron. *Swedish* iron and refined *Lowmoor* are said to be best. In the second instance, we can reduce the retardation by applying the fact, experimentally proved, that the shorter an electro-magnet is, the quicker is its action. If we, therefore, take $l + d$ constant, then the expression for ϕ —formula (21)—has a relative maximum for—

$$l = d \qquad \ldots \qquad \ldots \qquad (22)$$

which, in other words, means that we make the cross-section of each bobbin a square, when we have for the shortest possible length of the bobbin the largest amount of wire on it. M. Du Moncel stated that $l = 6\ d$ is the best; but this evidently cannot be adduced from Dub's experiments expressed by formula (19), in combination with the other experimental fact that the shortest cores act most quickly. Soft iron, powerfully magnetised, acquires and loses small increments of magnetism more readily than if in the neutral state. This is one of the reasons why polarised electro-magnetic instruments are quicker in action. Further, it is said to be best to have the iron cores projecting from the bobbin to a distance equal to half the diameter of the core. From theoretical considerations and practical experience, I am, however, inclined to believe that the projection of the cores should not be more than constructional reasons necessitate. In the case of horse-shoe electro-magnets, Count Du Moncel appears to have found by experiment that each core,

armature, and sole-plate should have about the same weight. Not unfrequently cores and armatures have been cut open in order to enhance the quickness of action. However, I am not convinced that this has such a beneficial effect. Experiments with differently shaped poles and armatures have given the result that, as a rule, it is best that the poles should have the same diameter as the iron cores with a perfectly plane attracting surface, and that the width of the armature should be equal to the diameter of the iron core. Further, solid cores and solid armatures appear to be the best both with reference to strength and quickness of action. The bobbins of electro-magnets must be filled *quite* uniformly with insulated copper wire of the highest conductivity procurable. The conductivity of copper wire in use in India must not be less than 95 per cent. of that of *pure* copper, a margin quite large enough for the supplies. The insulating covering must be quite uniform, and should consist of two layers put on the wire in two opposite spirals to a total radial thickness of not more than 0·025 mm. for thin wires. No paper is allowed between the different layers of the bobbin. Relay coils especially should be very carefully prepared.

VI. *Best Resistances of Receiving Instruments.*—This question can be solved from two very different aspects. In the first place, it may be thought of paramount importance to produce the largest amount of total magnetism in the iron core, independent of time, by a current passing through the convolutions of the coils. This question, *Maximum strength of signals*, has been satisfactorily solved. In the second place, although maximum strength may be highly desirable, it cannot and must not be considered as the principal question at issue, but the other question, *Quickness of action*, has to step into

its place. This last question, better expressed by *Minimum retardation of signals*, has not been investigated as yet in all its details, and is by far the more difficult of the two. In the following these two questions shall be treated separately :—

Maximum strength of signals.—If the dimensions and form of a coil are given, as also the resistance of the circuit external to the instrument, it is well known that any current, passing through the coils, has the greatest magnetic effect if *the resistance of the wire filling the given space is made equal to the external resistance.* From this, the conductivity of the wire material being given, the diameter of the wire can be calculated. The above simple rule, however, holds good only as long as the thickness of the insulating covering can be neglected against the diameter of the wire. This will be clearly the case for bobbins of large dimensions, especially when they are used in a circuit of comparatively low resistance. If, however, the bobbins are small, and especially when the external resistance is large, the diameter of the wire which has to fill the bobbins becomes small in itself, and hence to neglect the thickness of the silk covering against it would be wrong. In such a case, the rule is :—

*The resistance of the wire filling the given space must be smaller than the external resistance.** The law more definitely expressed is :—

The known external resistance must stand in the same ratio to the unknown resistance of the coils, as the total section of the wire (including the non-conducting section due to insulated covering) stands to the metal section of the wire; i.e.,

$$\frac{L}{x} = \frac{q + \Delta}{q}$$

* *Phil. Mag.*, vol. xxxiii. p. 29.

where L is the external resistance.

x the resistance of the coil.

q the metal section of the wire.

Δ the silk section of the wire.

As q contains x implicitly, the above formula does not give the value of x.

A very good approximate value for x is :—

$$x = L\,(1 - \sqrt[4]{L\,m^2}) \ldots \qquad \ldots \qquad (23)$$

where
$$m = \delta^2 \sqrt{\frac{c\,\pi\,\lambda}{A\,B}} \qquad \ldots \qquad \ldots \qquad (24)$$

If L and x are expressed in Siemens' units, then—

δ is the radial thickness of silk covering of the wire in mm.

λ the absolute conductivity of the wire material when the conductivity of pure mercury at the freezing-point is taken as unity.

B is the length of an average convolution expressed in metres.

A is half the cross section of the space filled with wire (*i.e.*, normal to the convolutions of the wire), expressed in square mm.

c is the coefficient which expresses how the space is uniformly filled with wire. For instance, if we suppose that, by filling the bobbin, we divide A into squares, then $c = 4$; if into hexagons, then $c = 3{\cdot}4$. It is generally believed that, in practical applications, the rough law is quite correct enough; the following two examples will, however, show that this is *not* the case.

EXAMPLES.—1. The external resistance to a relay is 5000 B. A. U.; it is required to determine the resistance of the wire which is to be used for filling the two bobbins in order to have the best arrangement.

The dimensions of a bobbin in Siemens' relay are :—

$$\text{Length of bobbin} = 40^{\text{mm.}}$$
$$\text{Outer diameter} = 32^{\text{mm.}}$$
$$\text{Inner} \quad ,, \quad = 10^{\text{mm.}}$$

Thus $$A = 440 \,\square^{\text{mm.}}$$
and $$B = 0{\cdot}0659^{\text{m.}}$$

The specification for copper wire provides that the conductivity of the copper should not be less than 50 at 80° Fahr., and that the radial thickness of the silk covering should not be more than 0·025 mm.

Hence $$\lambda = 50$$
and $$\delta = 0{\cdot}025^{\text{mm.}}$$

For c we will use the value 4, which theoretically represents the worst manner of coiling. It will, however, be clear that even this theoretically worst coiling will, in practice, never be approached.

Substituting these values, we get—

$$m = 0{\cdot}0029.$$

Further reducing the 5000 B. A. U. to Siemens' units, and calculating for one bobbin, we get—

$$\frac{L}{2} = \frac{5243}{2} = 2621{\cdot}5 \text{ S. U.}$$

Thus $$\frac{x}{2} = 2621{\cdot}5 \left(1 - \sqrt[4]{2621{\cdot}5\, m^2}\right) = 1611{\cdot}3$$

or $$x = 3222{\cdot}6$$

In this case the best value of the resistance of the relay is, therefore, 38 per cent. smaller than the external resistance.

2. The external resistance of a sounder is 30 S. U.; it is required to determine the best resistance of the wire which is to be used for filling the two sounder bobbins.

The dimensions of a sounder bobbin are:

Length of bobbin $= 58^{\text{mm.}}$
Outer diameter $= 35^{\text{mm.}}$
Inner „ $= 19^{\text{mm.}}$

Thus $A = 464 \square^{\text{mm.}}$
$B = 0{\cdot}0848^{\text{m.}}$

and again $\delta = 0{\cdot}025^{\text{mm.}}$
$\lambda = 50$
$c = 4$

Thus $m = 0{\cdot}00249$

and $\frac{x}{2} = 15\,(1 - \sqrt[4]{15\,m^2})$

or $x = 27$ S. U.

In this case, therefore, the resistance of the coils is 10 per cent. less than the given external resistance.

From x, the known resistance of the instrument, the diameter y of the bare copper wire can now be easily calculated, viz.: *—

$$y = -\delta + 2\sqrt{n + \frac{\delta^2}{4}}$$

Where $n = \sqrt{\frac{2\,A\,B}{c\,\pi\,\lambda\,x}}$

Thus we get $y = 0{\cdot}124^{\text{mm.}}$

the diameter of the wire with which the relay coils have to be filled.

And $y = 0{\cdot}497^{\text{mm.}}$

for the bare copper wire of the sounder.

These two examples show that, even for sounder coils, the correction is perceptible, but whether the correction is to be used or not, depends in each case on how accurately we know the external resistance, and if it re-

* This formula every one should try to develop for himself.

mains actually constant within the limits represented by the correction.

Minimum retardation of signals.—Before attempting a solution of this very intricate problem, it will be best to state clearly the different causes to which retardation of signals may be due. In Para. XII. it will be explained what is to be understood under *retardation of signals*, *i.e.*, the *received* signals *begin* and *cease* later than the *sent* signals. But there only one of the causes will be treated, viz.: *the charge and discharge of lines.* Although this cause has, no doubt, the greatest effect, still there remain two others which may also show some perceptible influence, especially if high-speed transmitters are employed. The separate causes of retardation are :—

Static induction of telegraph lines. This phenomenon will be fully explained in Para. XII.
Volta-induction of wire coils.
Magnetic inertia of iron core.

Volta-induction.—Suppose at first a very large bobbin filled with very thin copper wire in the usual manner of electro-magnetic coils, but *not* being supplied with an iron core. Further suppose the coil of wire *perfectly* insulated from earth and the convolutions from each other. We should then have an arrangement capable of showing the effect of volta-induction in its purest form. Now place in circuit with that coil a *battery*, a *key*, and an *aperiodic galvanoscope* * of very great sensitiveness, and with a magnet needle swinging infinitely quickly. Although such an instrument does not exist, we may imagine that we have one, in order to see the phenomenon in its purest form.

Now let us observe the needle of the aperiodic gal-

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* See p. 147, Vol. I.

vanoscope. On the very moment of closing the contact the needle will not move, but a little later a slight deviation will be observed, which gradually increases until, after the lapse of a certain time, the deviation of the needle will become constant. On the other hand, if we had no wire coil in circuit, and supposing that the coil of the aperiodic galvanoscope consisted of a few turns of wire only, then, repeating the above experiment, we should observe that deviation of needle and closing of contact would be perfectly simultaneous. Hence the gradual increase of the deviation of the needle from *nil* to a constant value, when the wire coil is in circuit, can only be due to the gradual increase of current, for we have supposed that the needle swings infinitely quickly, and that the galvanoscope is of great sensitiveness. This gradual increase of current is explained by *volta-induction of the wire coil*, or, which is the same thing, by the *self-induction of the wire-coil*, viz., the electrical excitement in a wire is not simultaneous in all its points, hence the current from the moment of making contact must be considered an *increasing* quantity. This increase, however, is so quick that it could not be well observed. But the current in its true nature remains, nevertheless, an increasing quantity. Therefore an induction current is set up in the coil itself, which is in an opposite direction to the primary current; and this induction current exists so long as the primary current still increases. The total effect of this must, therefore, be to retard more perceptibly the current flowing through the circuit. Hence, if the galvanoscope had not had any very great sensitiveness, but an essentially limited sensitiveness only—the actual case in practice—then clearly the deviation of the needle or *the signal* could only have been observed after the contact had lasted for a certain time. Therefore *volta-induction* or *self-induction* of a

wire coil will always retard the beginning of a received signal. Now shunt the battery by a resistance *nil,* but have the circuit otherwise in the same condition as before. What will then be observed? The moment we short-circuit the battery the needle will remain a very short time at its original deviation, but then will gradually return to zero. If we had made the same experiment, but without the wire coil in circuit, short-circuiting of the battery and returning of the needle to zero would have been perfectly simultaneous. This effect, again, is due to *volta-induction,* viz., at the moment of short-circuiting the battery, the current in circuit, in its true nature, is a *decreasing* quantity, but this decrease would be so quick that it could not be observed. However, the current is, nevertheless, a *decreasing* quantity, and therefore an induction current is set up in the coil of wire, which is of the same direction as the primary current. The total effect of this must be a retardation of the original current, or the end of a *received signal* is prolonged. If we suppose the length and section of the wire, of which the coil consists, to be constant, and only wind this given quantity of wire in different ways, it can be conceived that there must be a certain form of the coil in each special case, which gives the greatest amount of self-induction for unit of current. Gauss has investigated this problem and found that if the transverse section of a coil of wire is uniform throughout, and of circular shape, the following relation has to hold good between the mean diameter of the coil and the diameter of the circular transverse section.

$$D = 3{\cdot}22\, d$$

in order to make the coefficient of self-induction of the coil a maximum. D equals mean diameter of the coil, and d equals diameter of the circular transverse section.

If the transverse section of the coil is a square, the side of which is d, then the mean diameter of the coil should be—

$$D = 3{\cdot}7\, d\,*$$

In designing bobbins of electro-magnets for telegraph receiving instruments, therefore, all that we can do is *not to approach the above results.* In Para. V. it has been shown that the best shape of the transverse section of the bobbin is the square; and further, that the outside diameter of the bobbin should be three times the inside diameter. In this case, therefore, the mean diameter of the bobbin would be $D = 2\,d$, a result which does not at all approach the result for maximum self-induction. We may therefore be satisfied with the result.

Magnetic inertia.—If the bobbin considered before had contained an iron core, instead of being empty, then, qualitatively, there would have been no difference in the observed phenomenon; but the self-induction of the coil would have been greatly assisted by the increase and decrease of magnetism in the iron core, and consequently the total retardation would have been much more marked. Hence, when designing bobbins for electro-magnets, it will be still more requisite not to approach the best dimensions of bobbins for self-induction.

Telegraph signals, as a general rule, are produced by *closing* and *opening* the circuit. Hence retardation of the signals can only show itself principally during the *closing* of the circuit. On the *opening* of the circuit, the current has no time to flow, except through the short interval of time during which the opening spark exists. Hence working in *open circuit*, only the beginning of the received signal can be sensibly retarded by self-induction

* Clerk Maxwell, Vol. II., p. 312.

of the electro-magnetic coil; while when working in *closed circuit,* only the end of the received signal can be perceptibly retarded.

Static induction.—In the working of submarine cables and subterranean wires this represents the chief cause of retardation of signals; but in the working of overland lines, which have an electro-static capacity comparatively small, the effect of static induction on the retardation of signals becomes only practically sensible when the speed exceeds twenty words a minute on a line longer than 1000 miles (see Para. XII.). Now, as long as hand-signalling is employed, although an expert is able to receive and write down thirty-five words per minute, more than twenty words, during regular work, can scarcely be expected, and may be taken as a very fair practical working speed on overland lines. Hence, as a rule, the best resistance of relays will have to be determined on the consideration of *maximum strength of signals* only.

We may now sum up the results of this paragraph as follows:—The resistance of a relay for working overland lines, not exceeding 1000 miles in length, consisting of iron wire of a gauge *not* thinner than No. 24, I. W. G, and with a speed not greater than twenty words per minute, must be calculated by formulæ (23) and (24). The external resistance to the relay is, as a rule, a very variable quantity, and, therefore, a probable mean value should be taken (see Para. IX.). This will produce the maximum magnetic effect of the electro-magnet. Further, to have also the maximum attraction of the poles, the outside diameter of the bobbin should be exactly equal to three times the inner diameter, *i.e.*, the diameter of the iron core. Further, to reduce the retardation caused by self-induction and magnetic inertia to as small a quantity as possible, the best softest iron should be used, and the

iron core in each bobbin should have a length equal to its diameter. At the same time it has been shown that such an adopted form of coil does not approach in the slightest degree the best form for the self-induction of the coil.

VII. *Relays.*—To produce a clear and readable signal, whether a tap by a sounder or a mark by an inkwriter, the magnetic force produced by the arriving current must be of a certain strength depending on the construction of the receiving instrument. In some instruments the force required is very considerable. In sounders, for instance, the taps marking the beginning and end of the signals must be loud and distinct, so that there must be considerable tension kept on the antagonistic spring, and this has to be overcome by the electro-magnetic attraction of the armature. The force exerted on the armature of the Indian sounder when it is attracted with the standard force is about 340 grammes. Again, in the original Morse embosser, the force that was required for the style to indent the paper sufficiently to produce a good mark was still greater; whilst, in inkwriters, the force required to produce a mark by means of the revolving ink-wheel is reduced to a minimum. Strong magnetism requires a strong signalling current; but this cannot be obtained except in the case of comparatively very short lines. Hence there is a limit to the employment, as receivers directly from the line, of all instruments which, like sounders, require a considerable strength of magnetism to work them. In 1837, as stated before, Wheatstone overcame this difficulty by introducing the *relay*. The principle of the relay is, that the weak line current is received on a sensitive instrument, called a relay, which automatically repeats the signal on the receiving instrument by means of a local battery.

Thus the strength of the signal which is read is quite independent of the strength of the received line current: all that is required is that the received current is sufficiently strong to work the sensitive relay; and the strength of the signal may be made as strong as we please by augmenting the local battery.

Nearly all the lines in India are, on account of their great length, worked with relays; the only exceptions being short local wires, and the station to station wires of the State Railway Telegraphs, in which cases the lines are so short as to admit of direct-working sounders being employed. Even in the case of comparatively short lines there is an advantage in employing the relay, on account of saving of battery power.

Many different relays have been invented, but in India we only use two kinds—the Siemens and Halske polarised relay, and the D'Arlincourt relay. These alone will be described.

VIII. *Drawings.*—Electrical apparatus may be represented by *geometrical drawings;* by *perspective drawings;* and by *diagrams.*

Geometrical drawings, according to scale (plan, elevation, section), are generally only required in workshops. They must then contain all the constructional details whether essential or not. In some cases, such drawings may also become necessary in order to be able to explain fully the construction and action of an apparatus, especially when complicated. For instance, Hughes' printing instrument could not well be understood without geometrical drawings. But as a general rule, geometrical drawings are not required for explanation.

Perspective drawings, which are intended to give a picture of the apparatus, are of little use in practice, for, in the first place, they are difficult to make, and, secondly,

they are seldom capable of conveying to the mind a clear idea of the action of an apparatus.

Diagrams give the apparatus and its connections, not so much as it is actually made, but in such a manner as to exhibit the principles on which the apparatus acts in the clearest and simplest manner. Diagrams for explanatory purposes are, therefore, of the greatest use. It is advisable to adopt a uniform plan for representing the different parts of electric apparatus, and, if the diagram is well considered, there should be very few additional explanations wanted. The diagrams issued by *Messrs. Siemens Brothers* with their apparatus, as well as those given in *Sabine's Electric Telegraph*, are very good samples, and in this Department they should be imitated in all official reports. As the object of a diagram is to exhibit the principle of action in the clearest and simplest manner, it is obvious that it should not contain constructional details. For instance, screws which fix one part to another, but in themselves serve no electrical purpose, should not be shown in a diagram. A battery should be indicated by alternate short thick and long thin lines, the thick lines representing the negative poles, and the thin lines the positive poles of the cells, and not by actually drawing the jars, &c.

IX. *Siemens and Halske Polarised Relay.*—This practical instrument, invented by Messrs. Siemens and Halske of Berlin, has become extensively employed everywhere, and in India it has been almost exclusively used since the year 1859. The original construction and form of this instrument was so perfect and practically convenient, that it has never been changed in any of its essential parts, forming in this respect one of the very rare instances in telegraphy.

Short description.—To the *lower* pole, generally the

north,* of a strong permanent magnet (L shaped) are fixed two soft iron pieces, which, by induction, become magnetised at their free ends with the same polarity as that of the pole of the permanent magnet with which they are in contact. In our assumed case they have north polarity. By the *other* pole (south) of the L shaped permanent magnet a soft iron tongue, delicately pivoted on a vertical axis and swinging freely in a horizontal plane, is influenced. This tongue consequently also becomes a magnet with its south pole at its free end, and as this moveable south pole of the tongue is so arranged as to lie between the free ends of the two polarised soft iron pieces (two north poles, which we shall call in future the two *fixed poles* of the relay), the tongue is necessarily attracted by both these fixed poles, and the difference of the two forces exerted on the tongue represents the force by which the tongue is kept in its position of rest. To limit the play of the tongue, and also to introduce the contact for the local circuit, the tongue can be made to rest on the one side against an agate *rest contact*, and on the other side against a small screw tipped with platinum, the *working or local contact*. The tongue towards its free end, after it has passed the fixed poles of the relay, is made generally of brass, copper, or German silver, but might with advantage be made of aluminium, in order to decrease the weight of the tongue, and consequently the friction at its bearings.

On its side facing the local contact, the tongue carries

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* In these instructions the English and German mode of designating the two kinds of magnetism will be adhered to, *i.e.*, "the north pole of a magnet is that pole which, when the magnet in question is freely suspended and under no other magnetic influence than that of the earth, points towards the north." This definition certainly leads to the somewhat strange conception that the magnetism at or near the north pole of our planet is to be called "*south pole magnetism.*" The French definition is free from this inconsistency.

a small piece of platinum to secure a good contact between the tongue and the screw. By screwing the working contact nearer to or farther away from the rest contact, the *play* of the tongue can be regulated between zero and a certain fixed maximum limit. Further, the *rest* and *local* contacts being fixed to the same carriage, are moveable simultaneously by means of a micrometer-screw in a direction at right angles to the tongue. The force by which the tongue is kept in its position of rest (either resting against the agate or against the local contact) can be regulated with great nicety by this micrometer-screw, and can be made to vary between + and − limits going through zero. The soft iron pieces form the cores of coils, consisting of silk-covered copper wire of high absolute conductivity; both coils are connected successively, in such a manner that, when a current is made to pass through them, the free ends of the soft iron pieces, if they were not polarised already, become of opposite polarity, *i.e.*, forming a horse-shoe electro-magnet. The thickness of the wire of the relay coils of given dimensions, or its resistance, should be selected according to the resistance of the line on which the relay is to be worked; to which important question we shall revert further on. Each *fixed pole* carries a moveable shoe or armature of soft iron, by which the distance between the two fixed poles can be altered within certain limits. The whole arrangement described above is enclosed in a cylindrical brass box with a glass cover, which can be easily taken off when necessary. The micrometer-screw, for the purpose of conveniently adjusting the force by which the tongue is held in its position of rest, protrudes from the brass case, and can be taken out like a key. Each relay has four terminals, two of which are for the line circuit—representing, therefore, the two ends of the relay coils—the other two are for the local circuit, one

being in connection with the local contact screw, the other with the relay tongue. This description of the essential parts of a polarised relay is considered sufficient, as the relay itself is so well known, and as, besides, detailed drawings of it can be seen in any manual on telegraphy.

The working of the relay.—Suppose the tongue to be attracted towards the *rest contact, i.e.*, the tongue, by the help of the micrometer-screw, has been placed nearer to that fixed pole of the relay on the side of which the rest contact is situated, in which position the relay is ready for receiving when used in *open circuit*. Now, suppose that a current is sent through the relay coils in such a direction that it tends to make the fixed pole nearest the rest contact a south pole, or more generally a pole of the same polarity as the free end of the tongue, and that, consequently, it tends to make the other fixed pole a north pole, or more generally a pole of opposite polarity to the free end of the tongue; the magnetism of the pole nearest the rest contact is therefore decreased, while the magnetism of the other fixed pole is increased, and clearly, if the alteration made in the original magnetism of the two fixed poles by the current be sufficiently large, the force attracting the tongue may vanish, nay, even become opposite to that by which the tongue was kept at rest, and if great enough, the tongue will be thrown over from the rest contact to the working contact, where it will remain so long as the current in the relay coil persists. The moment, however, the current ceases, the magnetism produced by it in the fixed poles also ceases, and, consequently, the tongue must return to its original position of rest. Here we have tacitly assumed that the play of the tongue is exceedingly small as compared with the distance between the two fixed poles. If this were not the case, then, though the current would be able to

throw the tongue against the working contact, the mere cessation of that current would not be sufficient to bring the tongue back to its original position of rest, or in other words, the relay would *stick*.

Free movement of the tongue.—The tongue should move quite freely in a horizontal plane, and the vertical axis of the tongue should have sufficient play upwards. The best way of testing the free movement of the tongue mechanically is by taking off the nuts, removing the shoes, and holding a small magnet above the middle of the iron part of the tongue without touching it: the tongue should swing rapidly under the influence of this magnet, and should only come to rest after a great many swings; in fact, if the pivots be perfect, a tongue should *never* come to rest, but vibrate permanently under the influence of the test magnet. A magnetised penknife or a small screw-driver will answer well for a test magnet. This is, however, a test more required during the fitting up of the relay in the workshops than afterwards when in actual use. The pivots of the tongue should have a perfectly polished and smooth appearance under the magnifying glass. The holes in the bracket and the plate, which receive the two pivots, should be quite clean. To clean these holes, insert a small piece of wood, a pointed match, and turn it round sharply. An occasional use of the *finest watch oil* will prevent the pivots from rusting, but only a very small quantity should be used.

Play of the tongue.—The *play* of the tongue, *i.e.*, the fixed space between the rest contact and local contact, should be made as small as practicable, but large enough to ensure, with certainty, the break of the local circuit. The best way of finding this distance is by very gently screwing up the local contact screw until it just touches the platinum contact of the tongue, when the armature

of the receiver will be attracted, giving a sharp click, and then unscrew again very slowly, and stop as soon as the contact ceases, which will be indicated again by a sharp click of the receiver. Another equally good method, and the one generally employed in practice, is to adjust the play as finely as possible while the distant station is sending regular signals. It is clear that the smaller the play can be made the more sensitively the relay can be adjusted without sticking.

However, the play cannot approximate so closely to zero as would be required to have the maximum sensitiveness;* because, on the one hand, the spark, which, by virtue of the extra current, occurs when the local contact is opened, has always a certain length, and the play must, therefore, be invariably greater than the length of that spark; and, on the other hand, the tongue acting like a pendulum must have amplitude, in order to get sufficient acceleration to produce the pressure required to make the local contact securely. Further, since the free end of the tongue moves in a circle while the carriage moves in a straight line, representing a chord of this circle, it is evident that, if the "play" be made excessively small, on moving the carriage away in either direction from its central position, the end of the tongue will be jammed between the agate and the local contact screw; and, if the movement be persisted in, the agate may be broken and the platinum contacts injured.

Fixing of the shoes.—Suppose that the right distance between the two moveable shoes has been ascertained by experiment,† they should then be fixed tightly by the nuts, a key being provided for this purpose. The sides

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* This fact, combined with the friction of the pivots of the tongue, and the remanent magnetism in the shoes and cores, are the only reasons which prevent an unlimited sensitiveness of the relay.

† How this distance is to be found will be shown further on.

of the shoes facing the tongue should be parallel with each other, and with the tongue when the latter is in the middle between the shoes. These shoes, if seen to rust, should be cleaned and oiled.

Local contact screw.—It must never be attempted to turn the local contact screw for the purpose of adjusting the play of the tongue before having opened out the small clamping screw; and afterwards the latter should be securely fixed again, for if this be not done, the local contact screw works itself out, the play is increased, and the relay sticks.

Micrometer-screw.—This is used for moving the carriage to adjust the tongue between the two fixed poles, in order to increase or diminish the sensitiveness of the relay. This screw forms a most important part of the relay, and should move quite easily and uniformly, so that the slightest touch in one direction or the other may, with absolute certainty, ensure a displacement of the tongue. In some cases, as, for instance, when the screw has rusted in, a judicious application of watch oil may help. Great care should be taken not to turn this micrometer-screw in a rough and unintelligent manner, as, for instance, screwing the relay carriage with great force against the sides of the relay on either side when it cannot move any further. Such treatment will invariably result in bending the micrometer-screw, and in making the relay carriage shaky. Any relay in which the micrometer-screw does not move quite smoothly and uniformly, or which has a shaky carriage, must be considered imperfect and unsafe for regular working, because the position of the tongue cannot be adjusted with nicety, and, moreover, the tongue itself will not be stable in any one position. Such a relay should be invariably returned to the workshops. In order not to move the relay carriage unnecessarily, it should always be remembered that,

if the tongue is not attracted by the received current, relay too unsensitively adjusted for the current received, the micrometer-screw has to be turned from *left to right.* And that, when the tongue is sticking, relay too sensitively adjusted for the current received, the micrometer-screw is to be turned from *right to left.** It is in these pparently small but nevertheless important matters that a signaller can show himself to be an expert.

Never screw if you do not know beforehand in which direction to turn.

Platinum contacts.—These should be cleaned when necessary by using a little chalk on chamois leather; and on no account should emery or sand-paper be used, which would both spoil the surface and needlessly wear away the platinum. There is a tendency for the platinum to be burnt away by the spark of the extra current where the local circuit is broken at the contacts: this cannot be wholly avoided.† If it should be observed hat the platinum contacts are eaten away, it will be best to file both carefully down, and afterwards smooth and polish the surface with chalk and chamois leather. Any bazaar watchmaker will be able to do this.

* There are only a few relays in use where the reverse is the case.

† A coil of thin wire, offering a high resistance as compared with the total resistance in the local circuit, if connected with one end to the local contact screw, and the other end to the tongue, would reduce this spark considerably, but as a rule this remedy is not adopted because it is inconvenient and expensive. If the resistance of the receiver be selected with due reference to the internal resistance of the local cells employed, and if, besides, the receiver is in fair mechanical order, the required force for working the receiver can always be obtained, without producing a large spark at the platinum contacts.—This was written in 1869. At present, however, such shunts are employed. Experiments have shown that, if the resistance of a shunt is about ten times as large as the resistance of the sounder, the sparks disappear. Our sounders have a resistance of about 30 ohms, and to the shunt we give, therefore, a resistance of about 300 ohms. These shunts are made of the very finest German silver wire. Pencil marks, which would be still cheaper, we found too variable in resistance.

The platinum contact of the screw should form a small cylinder, terminated by a hemisphere of smooth and polished surface. The surface of the platinum contact soldered to the tongue should be perfectly plane.

Glass cover of the relay.—Never leave the glass cover off. On some of the relays the covers fit too tightly, and, consequently, the glass is often broken in trying to remove the cover. In such cases, the joint between the relay cover and the relay should be oiled, some fine sand or emery put on it, and the cover moved to and fro until it fits smoothly, and can be easily taken off. In order to avoid the breaking of the glass covers during transport, crossed slips of paper are generally pasted over it. This paper should be removed by wetting it, and not by using a penknife to take it off whilst dry. A relay when being returned to store should be invariably provided with paper pasted across the glass cover.

Indicator.—This consists of a small and light magnetic needle, delicately pivoted on a fine steel point. It is placed on the glass cover of the relay to indicate an arriving current, in case the relay, being either too sensitively or too unsensitively adjusted, should not be able to indicate the signals. These little indicators are eminently useful and practical, and *each relay should be provided with one.* In stations where the traffic is not continuous, and where a considerable time may consequently elapse between the receipt of successive messages, the adjustment of the relay which was right for the one message may be altogether wrong for the next, owing to the altered electrical condition of the line, and, therefore, this indicator becomes a most necessary adjunct to the relay. Besides, if in fair order, it will indicate currents far weaker than the relay itself, even when the latter is in its finest adjustment, and, consequently, it may be used for reading after the relay has ceased to

function. These indicators are supplied in two different forms, either quite separate from the relay, or fixed to the glass cover. For the relays used in duplex working, indicators are supplied of extraordinary sensitiveness, by which the balance for permanent and transient currents is adjusted. Of late, care has been taken to improve also the old pattern indicators. On the new relays lately issued, the small indicator needle is fixed to the glass cover. To have this needle in its most sensitive position, the relay cover must be turned so that the indicator needle is parallel to the tongue of the relay, and just over the local contact screw, when it will be seen that the blue or north end of the needle points towards the south pole of the permanent magnet. In this, clearly the most sensitive position, it may, however, happen that the needle has such a dip that it either touches the glass or the bottom of the little case, or both, the friction thus caused destroying its sensitiveness. To obviate this, a little wax should be carefully attached to the apparently light end of the needle until it is again horizontal. It is better, however, to keep the needle separate from the relay.

Best distance of the shoes.—Practice has shown that for each relay there exists a distance between the two shoes, which allows the greatest variation in the signalling currents for any fixed position of the tongue; or, in other words, the signalling current can alter within the widest limits, without a fresh adjustment of the tongue, by means of the micrometer-screw, being requisite. Hence, to find this *best* distance for each particular relay is of paramount importance. In the first instance, it is, however, necessary to show that such a *best* distance does really exist. This, without going into mathematical details, can be proved as follows:—Suppose the play of the tongue could be made

zero, then clearly the *best* distance of the two shoes for the weaker current would be the closest that the thickness of the tongue would allow of without actual contact taking place. A little greater distance than this, however, would be required in order to allow of the relay working, without sticking, with the stronger current. While, on the other hand, under the same circumstances, the *worst* distance between the two shoes would evidently be the largest that the construction of the relay would admit of. But as the play of the tongue cannot be made zero, even approximately, for reasons stated before, fixed length of the spark caused by the extra current, and required acceleration of the tongue to make a perfect contact, it will be clear that this possible minimum distance between the shoes must be wrong. Thus between these two limits, minimum and maximum distance of the shoes, there must be *one* which is the best, *i.e.*, *small* enough to work the relay safely with a very weak current, and *large* enough to work the relay safely with a comparatively strong current, without sticking. Then having this best distance, the force which keeps the tongue in its position of rest can be altered between 0 and a certain maximum by the use of the micrometer-screw, and currents of the greatest variation can be employed for working the relay. This best distance between the two shoes depends, however, on so many conditions, scarcely possible to express quantitatively, that it would be difficult if not impossible to calculate it. In fact, the best distance is so highly individual that the only accurate and convenient way to find it, is by experiment with each particular relay.

Exposure to the sun.—On no account are relays to be exposed to the direct rays of an Indian sun. The permanent magnet is sure to lose its magnetism perceptibly, and consequently the relay will become unsensitive.

Best resistance of the relay.—A very good value for the resistance of any relay is expressed by :—

$$R = \frac{5}{8} L^* \qquad \ldots \qquad \ldots \qquad (25)$$

where L is the *real* conduction of the longest section of line on which the relay in question is generally worked *direct.* Since 1872 the resistances of relays have been selected and distributed in accordance with the above rule, and this has greatly improved the working of the lines.

To ensure perfect insulation of the convolutions from

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* This formula has been obtained as follows :—

To obtain the maximum magnetic effect for any coil of wire of fixed dimensions, the resistance of the coil should be made equal to the external resistance through which it receives the current. Thus, in our case, equal to the measured conduction of the line, neglecting the resistance of the signalling battery.

If we suppose the resultant fault to be in the middle of the conductor, we have—

$$R = l + \frac{il}{i + l}$$

where $2\,l = L$ (real conduction of the line on which the relay works).

Now i is variable between 0 and ∞.

Thus for $i = 0$

$$R_0 = l$$

and for $i = \infty$

$$R\infty = 2\,l$$

or average

$$R = \frac{3}{2} l$$

Of this average it may, however, be said that it is too large, for not only has a line, especially a long one, an absolute insulation much nearer 0 than ∞, but also the best relay resistance is more requisite when the line is badly insulated than when highly insulated. Thus the average of the above average and the lower limit will give the best value that we can possibly fix by calculation, or

$$R = \frac{5}{8} L$$

each other, each coil is soaked in a mixture* of wax and resin, and then hermetically closed up by the same mixture, and covered tightly and neatly with strong leather. This, it has been found, is absolutely required in India during the monsoons, and the same precaution has been adopted for all other wire coils used for conveying an electric current. In the marine districts especially, protection for the coils against the corroding influence of the damp sea air is required; and since its general introduction (end of 1873) not one coil has been found corroded, as was formerly frequently the case.

Sensitiveness.—A well-constructed Siemens' relay of 500 ohms resistance, mechanically and electrically perfect, can always be worked *well* with a current equal to 2 Milli-Oersteds. Hence the current (c), required to work a Siemens' relay of resistance (r), of the same size, and with bobbins of the same dimensions, equally well, can always be calculated by the following formula:—

$$c = \frac{2\sqrt{500}}{\sqrt{r}} = \frac{44 \cdot 8}{\sqrt{r}} \text{ Milli-Oersteds} \quad \ldots \quad (26)$$

This formula is not absolutely correct on account of the silk covering of the wires; the convolutions of the same bobbin, filled with wire of constant conductivity, do not exactly increase with the square root of the resistance of the wire which fills the bobbin, but somewhat slower. Hence a high resistance relay has a disadvantage, and calculating by formula (26) we get the current too small. However, independent of this disadvantage, it has been stated that high resistance relays are objectionable for other reasons, *i.e.*, that in reality they are much more unsensitive than formula (26), even with correction,

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* Further on are given special instructions how this mixture is to be applied.

would indicate, and that moreover they very sensibly retard the signals. To investigate this the following experiment was made :—

Experiment.—A Siemens' relay wound with two coils of wire, very nearly equal in resistance, was used in this experiment. By means of a commutator the coils of wire could be conveniently connected either *parallel* or *successively*. A certain adjustment was given to the relay tongue, and then the smallest current found which just worked the relay regularly. In this manner the adjustment was sure to be the same for parallel and successive connection, *i.e.*, for low and high resistance relays, and, further, the effect of the silk covering was also eliminated.*

No. of Experiment.	Relay Coils Connected.	Relay worked well with one Cell through Ohms.	Remarks.
I.	Parallel . . Successively	4600 8000	Very finely adjusted.
II.	Parallel . . Successively	4600 7800	Same as No. I. Experiment.
III.	Parallel . . Successively	4200 7200	Somewhat less finely adjusted.

Before and after these experiments the resistance of the relay was measured and found to be—

$$\left.\begin{array}{l}\text{Parallel} \quad\quad\; = 754 \\ \text{Successively} = 3011\end{array}\right\} \text{ohms.}$$

The test cell, a Minotto, had a resistance of about 15 ohms.

* Because in this case double the metallic section of wire has also double the section of insulating covering.

If we call C the current required to work the relay when connected parallel, and c the current required to work the relay when successively connected, then from the above experiments we can easily calculate the ratio $\frac{C}{c}$, viz.:—

$$\text{From Experiment I. } \frac{C}{c} = 2{\cdot}05$$
$$\text{,, ,, II. ,,} = 2{\cdot}02$$
$$\text{,, ,, III. ,,} = 2{\cdot}06$$
$$\text{or mean, } \frac{C}{c} = 2{\cdot}04$$

But the ratio of the square roots of the two resistances of the relay is—

$$\frac{\sqrt{R}}{\sqrt{r}} = \frac{\sqrt{3011}}{\sqrt{754}} = \sqrt{3{\cdot}99} = 2 \text{ nearly.}$$

This is very close indeed. Further, it was ascertained by direct experiment that

$$\frac{C}{c} = \frac{\sqrt{R}}{\sqrt{r}}$$

kept practically constant, even for a working speed of upwards of thirty words per minute. Hence, in our application of relays for hand-signalling, there is no other disadvantage connected with high resistance relays than the influence of the silk covering.*

* The number of convolutions (n) of a bobbin filled *always* in exactly the same manner with wire of the same conductivity, and insulating covering of the same thickness, can be expressed as follows:—

$$U = \frac{r}{2w} + \sqrt{\frac{r}{v}} - \sqrt{\frac{r}{w}\sqrt{\frac{r}{v} + \frac{r^2}{4w^2}}}$$

(*Phil. Mag.*, vol. xxxiii. p. 32.)

Or, as vr is invariably very small as compared with $4w^2$, we have more simply—

Tests of the relay. Resistance.—Before being issued the resistance of the coils of the electro-magnet is carefully measured, corrected to the standard temperature of 80° Fahr., and marked on a brass plate attached to the board on which the relay is mounted. The resistances of the two coils of the relay, as indeed should be the case with those of all similar electro-magnets, should be approximately equal. This point is checked by measurements made in the workshop, before the instrument is fitted together. When an inspecting officer finds the resistance of a relay, according to his measurements, to differ more from the resistance marked on the board than can be accounted for by difference of temperature or observation errors, he must open the connections, take the relay off its base board, and measure the resistance of each coil separately.

$$U = \frac{r}{2w} + \sqrt{\frac{r}{v}} - \sqrt{\frac{r}{w}\sqrt{\frac{r}{v}}}.$$

where r = resistance of the wire filling the bobbin; r is therefore half of the resistance of the relay.

$$v = \frac{Bc}{A\lambda\pi} \text{ and } w = \frac{B}{\pi\delta^2\lambda}$$

where B = length of the mean convolutions of the bobbin.
A = transverse section of one side of the bobbin.
λ = conductivity of the wire material.
c = coefficient representing the manner of coiling. If by dividing A into squares, then $c = 4$; if into hexagons, $c = 3{\cdot}4$, &c., &c.

Hence v represents a very small resistance which is constant for any given bobbin filled always in the same manner with wire of constant conductivity, and with the same thickness of insulating covering. For a bobbin as used in Siemens' relay we have—

$$B = 0{\cdot}0659$$
$$A = 440 \,\square^{\text{mm.}}$$
$$\lambda = 55 \ (Hg = 1 \text{ at } 0^\circ \text{ C.})$$

and c we will take to be equal 4.

Further, $\delta = 0{\cdot}025$ mm. Therefore, for a Siemens' relay bobbin we have—

$$\left.\begin{aligned} v &= 0{\cdot}00000347 \\ w &= 0{\cdot}6105 \end{aligned}\right\} \text{S. U.}$$

*Insulation.**—Between the tongue and either terminal of the electro-magnet; between the tongue and the local contact screw, with contact between tongue

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and calculating U for relays of different resistances, we get the following table:—

Resistances of Relay in s. u.	U Number of Convolutions in *one* bobbin.
400	6178
500	6829
600	7406
800	8412
1000	9278
1200	10046
1400	10755
1600	11378
1800	11969
2000	12522
4000	16777

Using this table for comparing the sensitiveness of relays of different resistances, for instance:—A 500 relay and a 4000 relay, and supposing the 500 relay works well with 2 Milli-Oersteds; then a 4000 relay would work equally well with 0·81 Milli-Oersteds. On the other hand, if we calculate the current for the 4000 relay by the incorrect but simple formula (26), we should get 0·71 Milli-Oersteds, representing a calculation error of 0·10 Milli-Oersteds, or 14·1 per cent.

For a relay of lower resistance than 4000 the error would be less. This disadvantage of high resistance relays, due to the thickness of insulating covering, is, however, partly neutralised by the experimental fact, that, for a workman well up in coiling, it will always be easier to fill a bobbin uniformly with thin than with thick wire. It may, therefore, be said that the thickness of silk covering actually reduces the sensitiveness of relays very little indeed, supposing of course that higher resistance relays than 4000 are not used. The diameter of the bare copper wire in this case would be 0·113 mm. Much thinner copper wire cannot be well drawn. When the external resistance to the relay (in very long lines) should exceed 4000, it will be of advantage to increase the bobbins of the relay.

* When the relays are connected on boards, the test will not of course be taken actually between the parts of the instrument named, but between the several terminal screws in connection with these parts.

and contact screw broken; between rest and local contact.

Conduction.—Between the tongue and local contact screw, with contact between tongue and contact screw closed.

Mechanical execution.—See and inspect all the points of the relay which have been indicated in detail in the foregoing.

Performance.—Experience has shown that a Siemens' relay, if mechanically and electrically perfect, can always be worked with *one* volt through an external resistance equal to its own; and further that a distance between the two shoes can always be found, at which the same relay, with the same adjustment of the tongue, will work with 10 volts through an external resistance = 0 *without* sticking. Roughly, therefore, neglecting the internal resistance of the cells used for making the experiment, the range of a relay should not be less than *twenty.* Numerous experiments have proved that most of Siemens' relays can be adjusted to a far higher range. A great many are found over 35, and some have been found up to 55.

Any relay in actual use should give the *standard range* of *twenty* with certainty, and the range test is made in order to ascertain this fact. There are many causes * acting which may in time destroy the required working efficiency of relays, and consequently a simple test of efficiency becomes requisite periodically. In the following a short outline of the range test will be given

* The working efficiency of relays may be destroyed by the permanent magnet losing its magnetism; the tongue not moving freely; the play of the tongue being too large; the coils, one or both, having become shunted; the cores or shoes or both having become hard, and consequently retaining too much remanent magnetism; the platinum contacts not being metallically clean (sticky); the distance between the shoes being wrong; the magnet being cracked, &c.

as a guide. Practice, however, will better supply all the detailed information. Adjust the play of the tongue to its *minimum* as laid down before. Then work the relay, with one* cell through an external resistance equal to the resistance of the relay, and adjust the tongue as *unsensitively* as regular working will allow of. Then *without* altering that fixed position of the tongue,

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* As the dimensions of relay coils are generally the same for high as for low resistance relays, and as further the friction of the tongue and other mechanical imperfections in the construction of relays, can, as a rule, *not* be less for high resistance relays than for low resistance relays, but must be taken as equal, it will be clear that to use indiscriminately *one volt* in the lower limit test, imposes rather a severe condition on the relays of high resistance. In fact it will be clear that if a certain E. M. F. has once been fixed to produce the minimum force with which a relay of given resistance works satisfactorily, the E. M. F. required to work another relay of another resistance with the same minimum force cannot be the same, but must certainly be an increasing function with the resistance of the relay under test. For instance say we have two relays identical in everything but in the resistance of their coils. The one relay is filled with thin wire offering a resistance R, while the other is filled with thick wire offering a resistance r, then the minimum force which works the two relays is expressed respectively :—

$$p = \frac{E\sqrt{R}}{2R + F} \text{ (high resistance relay)}$$

and $$P = \frac{e\sqrt{r}}{2r + f} \text{ (low resistance relay)}$$

But as $P = p$ necessarily, we have

$$E = \frac{2R + F}{2r + f} \cdot \frac{\sqrt{r}}{\sqrt{R}} \times e.$$

Suppose F can be neglected against $2R$, and f against $2r$, we have more simply

$$E = e\sqrt{\frac{R}{r}}$$

which is the required function.

In practice we find it is sufficiently accurate to use for relays with resistance under 1000, *one* volt; and over 1000, *two* volts. And for the higher limit tests of course 10 and 20 volts respectively. Greater justice would be attained by constructing a table.

i.e., without touching the micrometer-screw, the relay should work *without* sticking with 10 cells through no external resistance. The reverse method may also be adopted, and in fact is preferable. Work the relay with 10 cells through an external resistance equal zero, and adjust the tongue as *sensitively* as the regular working of the relay will allow of (without sticking), then without altering the position of the tongue by the micrometer-screw, work the relay with one cell through an external resistance equal to its own. If, in either case, the relay works regularly, even if worked alternately with the strongest and the weakest current, and not the slightest irregularity in the signals is observed, the relay is in perfect working order, is properly adjusted, and has the required standard range of twenty.* If a relay does not stand this test, then after it has been carefully ascertained that the play of the tongue was a minimum during the experiment, the next trial is to judiciously adjust the distance between the two shoes, either increasing or decreasing it as the case may require. If no such distance can be found at which the relay has a range of twenty, then other experiments become requisite to find the cause and introduce a remedy.

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* E. M. F. of one cell $= e$; internal resistance of one cell $= f$; resistance of relay $= r$.

Then the weakest current working the relay is—

$$c = \frac{e}{2r + f}$$

and the strongest current working the relay is—

$$C = \frac{10\,e}{r + 10f}$$

$$\therefore \qquad \text{Range} = \frac{C}{c} = \frac{10\,(2r + f)}{r + 10f}$$

If $10f$ is very small as compared with r (which is invariably the case for high resistance relays), then Range $= \frac{C}{c} = 20$ approximately.

First, see whether the resistance of the relay is correct. Further, clean the pivots of the tongue, and the holes in which they play, wipe the platinum contacts, and if this does not have the desired effect, anneal the shoes, and even if necessary the iron cores, in a charcoal fire. An excessive amount of remanent magnetism, which may be caused by the cores or shoes having become too hard, must necessarily greatly interfere with the range of any relay. If no remedy can be found to bring the relay up to the standard range, then it is to be returned to Stores, with a short statement of the experiments made.* The actual experiments required for the range test are very simple. If an adjustable resistance box is available, the two experiments, for weakest and strongest currents, can be made most conveniently; but if such a box is not available, there can always be found coils of wire of known resistances, as, for instance, the resistance coils in the tangent galvanometer, the coils of other relays, &c., which may be used as external resistance in the one experiment (weak current). It is then only necessary to ascertain first what E. M. F. is approximately required to produce that weak current. The other E. M. F. for the strong current, remains the same, either 10 or 20 as the case may be.

For instance, say a relay is to be tested for efficiency which has a resistance = 450. Then the weakest current that it has to be worked by is

$$c = \frac{e}{2 \times 450} = \frac{e}{900}$$

But there is no external resistance = 450 available—

* Cases have occurred where relays have been rejected and returned, which, when tested at the workshops, were found perfect. This proves that the experiments were conducted in a careless and unintelligent manner. Officers in charge should be careful, and should verify their results before finally rejecting relays.

only the 2000 resistance coil of the tangent galvanometer—then

$$c = \frac{xe}{450 + 2100}$$

From which follows $x = 2{\cdot}8$ cells, say 3 cells, the E. M. F. required to produce the weak current; while 10 cells are to be taken to produce the strong current; and similarly in any other case. Generally $x = \frac{r + w}{2\,r}$ approximately, where w is the "added" resistance. Each relay, before issue, is tested for range, and its range is marked on the board. On receipt, it should be tested for range before being brought into use, and as the shoes are fixed at their best distance, they should not be altered unless necessary. Remove carefully the small cork pieces between tongue and shoes. The officer in charge should keep the key for adjusting the distance of the shoes, and signallers are not allowed to open the glass cover of the relay, or adjust the distance of the shoes. When once the best distance between the shoes has been fixed, it will always remain the best distance, unless the relay be spoiled.

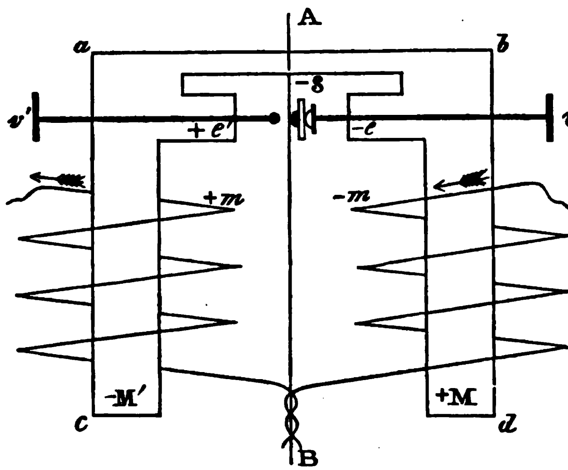
X. *D'Arlincourt's Relay.*—The construction of this instrument is based on a partly novel principle, which can only be made clear by giving a detailed description of its essential parts. As an experimental trial, four of D'Arlincourt's relays, complete with discharging arrangements, were introduced at the beginning of 1874, on one of the Bombay-Jabalpur-Calcutta main lines (sections 850 and 640 miles long), where they have been at work ever since. The actual result of this trial, as also the experimental results obtained in the testing room, will be given further on.

Description.—In its elementary form D'Arlincourt's relay may be represented as in Fig. 3.

a b c d is a soft iron core in the shape of a horse shoe, cut out in the middle in a peculiar manner, as indicated in the figure. Each arm of the horse shoe carries a helix of insulated wire, connected up successively in such a manner that a current passing through the coils will transform the horse-shoe soft iron core into an electromagnet with the neutral line *A B*.

s is a soft iron tongue, pivoted finely on a vertical

Fig. 3.



axis, and moving freely in a horizontal plane. This tongue is strongly polarised by being pivoted in close proximity to one of the poles of a powerful permanent magnet. The free end of the tongue (which in the figure is indicated by *s*, the permanent magnet and the pivoted part of the tongue are not shown in the figure) plays between the two limiting screws *v* and *v'*, in the vicinity of the neutral line *A B*, and within the cut out space of the iron core, which has the projecting nuts *e* and *e'*. One of these screws, say *v*, serves as the

rest contact, while the other v' represents the local contact; the latter is platinum tipped.* Further, the tongue, opposite the local contact screw, is also of course faced with platinum, in order to secure a perfect contact for the local circuit. Either of the two screws, v and v', can be adjusted separately to get the right "play" of the tongue. Further, by means of a micrometer-screw the relative position of the tongue s, with respect to e and e', can be adjusted with nicety. This can be done either by leaving e and e' fixed, and moving the tongue together with its limiting screws, as in the Siemens' relay, or by keeping the tongue and limiting screws fixed, and moving e and e' simultaneously in the *same* direction, as D'Arlincourt has done.† The micrometer-screw has not been shown in the drawing, for it is not intended to give a picture of the instrument as it is, but only to exhibit clearly, and without complication, the principle of the relay.

Principle of action.—In order to get a clear understanding of the action of this relay, we must consider it under three different conditions:—

Firstly, When no current passes through the relay coils.

Secondly, When a permanent current passes through the relay coils.

Lastly, When this permanent current ceases.

When no current passes through the relay coils.—Then the horse-shoe core, consisting of perfectly soft iron, may be considered as containing no perceptible

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* In the instruments received the other screw v is also platinum tipped, but might of course carry an agate as in Siemens' relay.

† In fact D'Arlincourt has adopted the still simpler adjustment—*i.e.*, he keeps e and e' fixed, and alters only the quantity of iron acting in e on s by a micrometer-screw of large diameter. If this screw is screwed in as far as it can go, then the action of e on s is greatest.

magnetism in itself. But the free end of the tongue, being strongly polarised by a powerful permanent magnet, induces magnetism in the projecting nuts e and e', which is of an opposite kind to that contained in the free end of the tongue. Thus the two forces acting to move the tongue will be opposite, and the force by which the tongue is kept at rest will be the difference between these two forces. It is clear that by altering the relative position between the tongue s and the nuts e and e', this difference of forces may be varied between two given limits + and — going through zero, and this, as mentioned before, can be always done, with any required amount of nicety, by the micrometer-screw. Thus placing, for instance, the tongue very much nearer to e than to e'—*i.e.*, screwing the micrometer in—the tongue will rest with a certain force against v. Supposing this to be the case, the relay is ready for receiving when worked in *open circuit.* The force, by which the tongue rests against the rest contact v, we will call, in future, the *rest force*, and it shall be designated by r. Further, if we call l the friction in the pivots reduced to the same point where r acts, then any force f, which acts on the tongue at the same point in the opposite direction to r, will be able to throw the tongue against v', if

$$f > r + l$$

and as soon as f ceases, the tongue, by a force $r - l$, will return to its original position of rest; supposing of course that the play of the tongue is so small that r and l are both sensibly constant with respect to all positions of the tongue between v and v'. As l, the friction, acts necessarily against the motion of the tongue in either direction, it should be made as small as possible in order to secure prompt movements of the tongue; and for

this reason great care has been bestowed on the pivoting of the tongue, and also its weight has been made very small. This of course is equally requisite in any other relay that is constructed to indicate weak currents with great regularity.

When a permanent current passes through the relay.—This current has two different actions:—

Firstly, It transforms the horse-shoe soft iron core into an electromagnet, say with a positive pole ($+ M$) at d and a negative pole ($- M'$) at c. Therefore, the nuts (e and e') not being in the neutral line A B, e will receive $-$ polarity and e' $+$ polarity. The new force, which we will call f, exerted by the nuts on the tongue, is clearly opposite to r, and by it the tongue will move from v towards v', if

$$f > r + l.$$

Secondly, The current, passing through the relay coils, will make them act like a magnet with opposite polarity at their extreme ends—namely, in our assumed case the extreme end of the left coil, where the current leaves, becomes $+$ polarised (so that it would attract the $-$ pole of a magnet), while the extreme end of the other coil, where the current enters, becomes a $-$ polarity. The force exerted by the direct action of the coils on the tongue we will call f'; it is invariably of the same sign as f. The magnitude of this force f is proportional to the current passing through the coils, and to the amount of magnetism lodged in the tongue; f becomes the larger the nearer the two extreme ends of the coil approach the tongue, and the more parallel the plane of the convolutions is to the tongue. Under the action of a current the tongue will move from v towards v', if,

$$f + f' > r + l$$

Now the direct action of a current on a moveable magnet may be considered as instantaneous, and therefore f' will not only attain its *maximum* in an imperceptible time, but will also become zero in an equally small time, whenever the current ceases. Thus, if f' could be made very large as compared with f, such a relay would evidently work very quickly, and this D'Arlincourt has achieved, *not* by making f' absolutely as large as possible, as should apparently have been done, but by making f as small as possible—*i.e.*, the tongue of D'Arlincourt's relay is rightly placed, but the convolutions appear not to be so.

When the permanent current ceases.—As already stated, the force f' becomes zero instantaneously, while the magnetism in the horse shoe ceases gradually, namely, in the following manner: $+e'$ and $-e$, as well as $-M'$ and $+M$, neutralise their respective magnetism through the soft iron, and as the distance between the two nuts ($\pm e$) through the soft iron is smaller than the distance between the two poles ($\pm M$), it is clear that the neutralisation must be in the first case more rapid than in the second; and as besides $e < M$ invariably, it is clear that a moment after the circuit has been opened, the magnetism in the two nuts must become reversed, or a force Δr is exerted on the tongue, which is of the same sign as r, the rest force; whence it follows that the tongue must return from v' to v with a greater decision than if r acted alone.

Δr being, however, a force of an essentially transient nature, it will be zero when the tongue arrives at v, when therefore the tongue is again in its original sensitive position, ready to indicate a second signal. This application of the remanent magnetism to bring the tongue back to its original position of rest, is entirely novel and constitutes *the great advantage* of D'Arlincourt's relay.

From the above the action of D'Arlincourt's relay will be clear, namely:—

(a.) The force which keeps the tongue at rest, when no current is passing through the coils, is due to induced magnetism in the tongue and nuts, which is essentially the same as in the Siemens' relay.

(b.) The force which moves the tongue from its position of rest, when a current passes through the coils, is due to the combined action of two forces exerted on the tongue, invariably in the same direction, viz.: the one due to the magnetism produced by the current in the nuts, and the other due to the direct magnetic action of the current in the helices—again essentially the same as in the case of Siemens' relay, with the exception that in D'Arlincourt's relay the force due to the nuts has been reduced in absolute magnitude—a step in the right direction—while the force exerted directly by the current has been kept small as in Siemens' relay—in this respect the construction of the relay appears faulty. The latter force being essentially instantaneous, should apparently be made as large as possible by placing the coils close to the tongue, and the plane of the convolutions parallel to the tongue.

(c.) The force under which the tongue returns to its position of rest when the current in the coils ceases, is temporarily augmented by the neutralisation of magnetism through the soft iron core. This ingenious application of the residual magnetism constitutes the novelty of the relay, and considerably increases its safe and regular working.

Thus it will be apparent in what direction D'Arlincourt's relay might be improved upon in order to obtain a relay fulfilling the following desirable conditions: delicacy of adjustment, quickness of action, and large range.* The special instructions given for Siemens' relay, with respect to mechanical condition, adjustment, and maintenance, are equally applicable to D'Arlincourt's relay.

Note.—Mr. D'Arlincourt, in the *Journal Télégraphique* for 1872, has given an explanation of the working of his ingenious relay that appears scarcely reconcileable with physical facts. In the first place, he assumes that a current passing through the coils will magnetise the soft iron core in such a manner that the whole of the horse shoe situated on the one side of the neutral line *A B* (Fig. 3) will become of one polarity, while the whole of the other side will assume the opposite polarity—*i.e.*, that the nut e' will be of the same polarity as the extremity M', and the nut e of the same polarity as the extremity M. Such, however, is not the case. When a current is passing, e' is actually of opposite polarity to M', while e is opposite to M. In the second place, he states that the direct magnetic action of the posterior ends of the bobbins on the polarised tongue, is opposite to that exerted by the nuts, whereas both forces have invariably the same sign; and thus his conclusion that the force exerted by the magnetised nuts on the polarised tongue is opposite to the force directly exerted by the current in the wire on the tongue, appears also erroneous. He further assumes not only that the direct magnetic action of the current in the bobbins, disadvantageously placed as they are, is sufficient to move the tongue, but also that it is stronger than the force exerted by the magnetised nuts. This

* It might lead to considerable improvement in the construction of polarised relays if some one were to take the trouble of developing the equations of motion of a relay.

also appears wrong. By placing the tongue close to the neutral line $A\ B$, D'Arlincourt has considerably decreased the force exerted by the cores, but he has not thereby increased the force exerted by the bobbins, the plane of the convolutions being normal to the plane of the tongue. I point these facts out, not to disparage the value of Mr. D'Arlincourt's invention, which is unquestionably an improvement on all pre-existing relays, but in the endeavour to explain its mode of action on rational principles.

Tests of D'Arlincourt's relay.—It is not necessary to specify them, since they are the same as those given for Siemens' relay.

XI. *Discharging Arrangements.*—These are required for long overland or submarine lines, in order to cause the received signals to be sufficiently regular and distinct for safe reading. Before describing, however, the special means which may be adopted for this purpose, a concise statement of the *phenomenon* itself, which has been named *charge and discharge of telegraph lines*, shall be given.

XII. *Charge and Discharge of Telegraph Lines.*—Fig. 4 gives a diagram by which the phenomenon in question can be generally and conveniently explained.

G' and G'' are galvanometers suitable for reading deflections, or better, for measuring currents.

k is a double key.

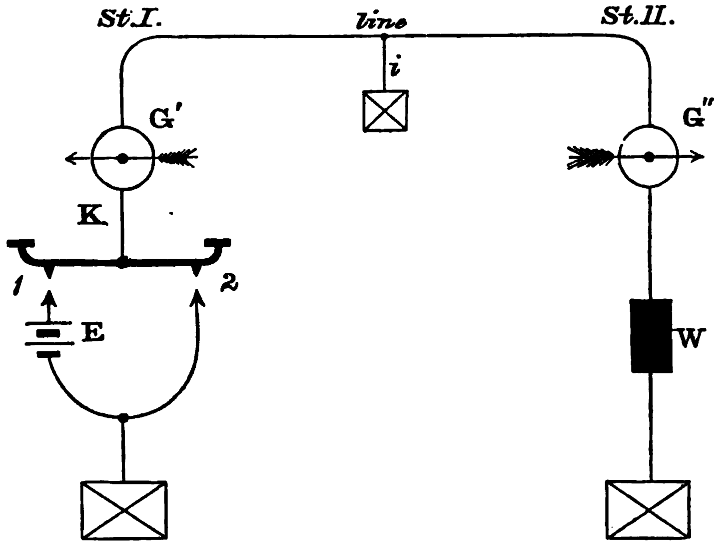
By closing contact 1, G' is brought into contact with the insulated pole of the battery E, the other pole of which is connected to earth permanently. By closing contact 2, G' is put direct to earth.

i is the resistance of the resultant fault of the line connecting Stations I. and II.

W is any resistance through which G'' in Station II. is connected to earth.

To show the phenomenon of "*charge and discharge*" unaffected by secondary influences, we shall suppose that no *natural current* exists in the line; thus, on closing contact 2, neither of the two galvanometers would show a current. At the moment of making contact 1, G' will indicate a strong current, while G'', if it could be observed, would show no current. Further, keeping contact 1 closed, it will be observed that the current in G' gradu-

Fig. 4.



ally decreases, while the current in G'' gradually increases. The increase of the current in G'' is slower than the decrease of the current in G'. The variation of the currents becomes, however, smaller and smaller with the time contact 1 lasts, until, after a certain time, the two currents remain practically constant—theoretically they can only become constant in an infinite time. When this approximate constancy of the currents is obtained, the dynamic balance for the system is established; *i.e.*,

the quantity of electricity which passes in any given time through G', from the battery, into the line, is equal to the sum of the currents which pass through i (leakage) and through W to earth in the same time. But before this state is arrived at, the quantity of electricity that enters G', in any given time, is always larger than the sum of the quantities that pass through i and W to earth in the same time. What, then, becomes of the part of electricity which enters G' and does not appear in the form of current either at i or W? This part of the electricity, which is apparently lost, is employed in raising the potential of each point of the line; *i.e.*, in statically charging the line. Therefore this phenomenon has been appropriately called *the charging of a telegraph line.* The line is fully charged if the potential at any point of the line keeps constant with respect to time, when, consequently, the currents observed in G' and G'' will also remain constant. The time required for fully charging any given line is a known function of its mechanical and electrical condition. Thus the current c_t, which at any time passes through G', may be considered to consist of two terms, both being invariably of the same sign. The one term is the current c, which passes through G' after the line is fully charged, and the other term Q_t, is the current due to charge at the time t. As the zero point of time we use, naturally, the moment contact 1 is made.

Thus $$c_t = c + Q_t$$

If we call T the time at which the charging of the line is completed, then we have

$$c_T = c$$

and $$Q_T = 0$$

The current Q_t is called the *transient* current, the current c the *permanent* current, and the current c_t the *true*

current. If we now open contact 1, but do not close contact 2, we shall observe that the current in G' ceases instantly, while the current in G'' keeps constant for a moment, and then decreases; until, after a certain time, the current in G'' also becomes zero. Where, then, does this current come from, which passes through G'' long after the battery has been taken off? This current is due to the potential of each point of the line reducing itself to the potential of the earth, by transfer of electricity, through i and W; *i.e.*, by the line losing its charge: consequently, this phenomenon has been appropriately called *the discharging of a telegraph line.* If, upon opening contact 1, we had at the same time closed 2, the discharge of the line would have taken place through both stations and i, and the discharge in station I. would have shown itself as a very strong current, opposite in direction to the charge current. The above-stated phenomenon of charge and discharge is quite a general one; *i.e.*, it may be observed with any form of conductor placed under any condition: but it can be well observed on long overland lines, and still better on long submarine cables, since, in such cases, the transient currents are not only absolutely large, but also relatively large, as compared with the final permanent currents. In fact, it was with cables (subterranean) that the phenomenon of charge and discharge was first discovered.*

* The charge and discharge of telegraph lines was observed by Messrs. Siemens and Halske, and by Mr. Kramer in 1848, when trying to work through the subterranean cable between Berlin and Cologne. The telegraph signals could only be made to pass with difficulty and exceedingly slowly, and, after ascertaining that it was not due to the imperfection of instruments or to leakage, Dr. Wr. Siemens as well as Kramer gave the right explanation of this novel and interesting phenomenon. The retardation of signals was due to the statical charge of the cable. It must be remembered that the subterranean cable Berlin-Cologne was the first long one used for telegraph operations. In 1850, Dr. Wr. Siemens and Guillemin made exact experiments on the sub-

If we now suppose the line perfectly insulated ($i \doteq \infty$), and also its remote end insulated ($W = \infty$), then the current observed in G', on closing contact 1, will be entirely due to charge, and will, therefore, become zero, when the line is fully charged; while the current in G' will clearly keep zero during the whole time contact 1 lasts. If we, then, open contact 1 and close contact 2, no matter what length of time elapses between these two operations, a discharge current will be observed in G' opposite to the charge current, and, clearly, the whole quantity of electricity which discharges itself through G' must, in this case, be equal to the charge; for, on account of $i = W = \infty$, no electricity can escape otherwise than through G'. This represents the case where the phenomenon of charge and discharge is most clearly shown, long and perfectly insulated submarine cables insulated at their remote end. But if we suppose $i < \infty$, the amount of discharge observed in G' will be smaller than the charge, and will decrease in a

ject. Later on (*Pogg. Ann.*, vol. cii. p. 66), Dr. Wr. Siemens gave the general laws of charge and discharge as found by experiments. It is interesting to mention that Ohm, so long ago as 1820, predicted the phenomenon of charge and discharge, since, when investigating mathematically the propagation of electricity in linear conductors, he not only introduced in the differential equation the lateral loss by leakage (conduction of air), but also used a certain co-efficient, which represented that peculiarity of electricity, that different points of the linear conductor may require different quantities of electricity to raise their potential to a given amount. This co-efficient is nothing else than what later on was called the *Inductive Capacity* of the point in question (see Appendix I., vol. i. p. 41). In fact, *all* problems, a solution of which may be required for telegraph lines, follow directly from Ohm's general équation; it is only necessary to introduce the newly-defined quantities. Sir W. Thomson has applied Ohm's equation in his paper "On the Theory of the Electric Telegraph," *Phil. Mag.*, vol. xi. p. 146. For further reference, see Maxwell's treatise on *Electricity and Magnetism.*

Dr. Werner Siemens also pointed out that the phenomenon of charge and discharge was not only restricted to cables, but might also, though to a less extent, be observed on long and well-insulated overland lines.

certain rate with decreasing i and with an increase of the time which elapses between the two operations, breaking of contact 1 and making of contact 2. Further, this discharge through G' will become still smaller when the remote end of the line is not insulated, but connected to earth by a resistance $W < \infty$. This represents, in fact, the case we have to deal with in practical telegraphy. From the above it will be clear how the charge and discharge must influence the speed and regularity of telegraph signals.

To avoid circumlocution we will define the following terms:—

Sent-signal.—This is begun and ended by a distinct operation—namely, the make and break of one and the same contact, by the key of the sending station. The time during which the contact lasts is the *length of the sent-signal.*

Received-signal.—This is given by the receiving instrument of the receiving station as a consequence of the sent signal, and is begun and ended by the make and break of one and the same contact—namely, that of the relay. The time during which this contact lasts is the *length of the received-signal.*

Non-signal.—In order to separate any two successive sent-signals, and consequently also their counterparts—the received-signals—it is necessary to leave the key at rest for a certain period between any two successive sent-signals, during which *no* signal is sent, and *no* signal is received. The time during which this *non-signal* lasts is the *length of the non-signal.*

Thus it will be evident that telegraphic communication would be most perfect if *sent-signals, received-signals,* and *non-signals* could be made very short; this constitutes the *rapidity of signalling.* Further, that each *received-signal* should begin and end simul-

taneously with its corresponding *sent-signal*, when necessarily they would also be of equal duration, and successive *received-signals* would be separated by *non-received-signals* of equal duration with the *non-sent-signals*. In other words, the *received-signals* would become perfect copies of the *sent-signals*, and successive *received-signals* would be entirely independent of each other, as they ought to be: this constitutes the *regularity of signals.*

Observed under certain conditions, as in a flash of lightning or in the spark from an electrical machine, electricity would appear to be transmitted with a velocity so exceedingly great as compared with the longest distances on our planet, that the greatest perfection of telegraphic communication (as described above) might seem to be easily attainable. However, even disregarding the imperfection of receiving instruments (sluggishness of action), a practical limit to the velocity of telegraphing is soon reached owing to the phenomena of inductive capacity, and such desirable perfection of communication unfortunately rendered impossible over even comparatively short distances, especially if the lines contain cables, submarine or subterranean. On account of charge the *received-signal* clearly begins later than the *sent-signal*, and on account of discharge in the receiving station, the *received-signal* also ceases later than the *sent-signal.* This constitutes the *retardation of signals.* Further, the retardation, it will be clear, must become greater and greater, the faster sent-signals follow each other; for after each signal sent, there is a discharge commenced in the sending station, which must partly neutralise the next following charge, supposing that the signals are produced by currents of the same sign. Hence the great benefit of using alternately positive and negative signalling currents. To sum up, the effect of

charge and discharge will be, that the *received-signals* must invariably become longer than their respective *sent-signals*, of which they should be perfect copies, and that by this the proportion of the length of the *received-signals* and *non-signals*, which by any adopted alphabet is always fixed, must undergo variation—*i.e.*, that the *received-signals* must become unreadable, having a tendency to run together. This they actually do, if the signalling speed exceeds a certain limit. Hence there is a certain speed of signalling on any particular line (this speed depends on the length of the line and its electrical condition) for which the signals are still readable, and this practical maximum speed of signalling represents the *mercantile value* of the line. On long overland lines, at least on the longest lines worked direct in India, 850 miles in length, and consisting of No. 5½ B. W. G. wire, the effect of charge, so severely felt to interfere with the speed and regularity of signals in long submarine cables, is still imperceptible for the maximum working speed, thirty-five five-letter words per minute, obtainable by hand-signalling, and with it we have therefore nothing to do here. In fact, a signal sent from Calcutta to Agra direct, begins and ceases at Calcutta and Agra practically at the same time, even when sending at the high speed of thirty-five words per minute.

The other effect, however—*the discharge* of the line through the sending station after each signal sent—affects most seriously the relays of the sending station, and it is the elimination of this effect for which *discharging arrangements* are required.*

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* The method of a station permanently cutting out its own relay whilst sending, has never been adopted in India; for however perfect lines, instruments, and operators may be, it is *always* desirable that the receiving station should be able to call the sending station at any moment during the transmission of a message.

XIII. *Discharging Key.*—The principle of such an arrangement will be clear from Fig. 5, which represents the diagram of a *discharging key*.

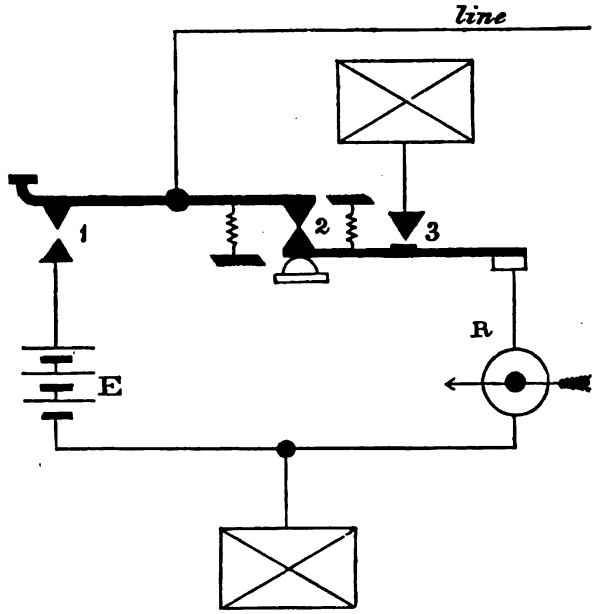
1, 2, and 3 are adjustable electrical contacts.

R is the receiving relay.

E the signalling battery.

When the key is at rest, *i.e.*, ready for receiving a signal from the distant station, then contact 2 is *closed* and contacts 1 and 3 are *open*.

Fig. 5.



When the key is sending, then contact 2 is *open* and contacts 1 and 3 are *closed*. Hence, between the sending and the receiving position of the key, there will be a position in which contacts 2 and 3 are *closed* and contact 1 is *open*. Thus, if contacts 2 and 3 are made to last simultaneously for a sufficient interval of time, the discharge from the line may escape through 2 and 3 to

earth, instead of passing through the relay when the final rest-contact is made. By the use of well-tempered springs, and by the careful adjustment of the play of the three contacts, the time during which contacts 2 and 3 last simultaneously, may be prolonged to such an extent as to almost wholly discharge the line during the interval.

In case it should be found that the contacts 2 and 3 do not last together long enough to discharge the line effectually, a small battery may be introduced between 3 and earth, which sends a charge into the line, opposite and equal to the remaining discharge. Practice, however, has shown that such a battery is not required. The discharging key can always be adjusted in such a way that any remaining discharge through the relay is too weak to affect even the most sensitively adjusted relay.

It will be cléar that the same arrangement can be adopted in translation stations, if it be only remembered that in translation stations the armature of the sounder acts as the key for automatically re-transmitting the message.

Weak springs, especially when they are much used, easily get out of order. Further, the play of the key, for convenient working,* cannot be made very large, and the play of armatures in translation stations, must be made still smaller, in order to keep up the maximum speed. All these introduce some obstacles to the practical use of discharging keys and armatures, and if, therefore, another equally efficient method, not labouring under these practical difficulties, could be found, it would be a decided advantage. See the following arrangements.

* It is true that the difficulty might be overcome by using a local current to work an armature which acts as the discharging key; but this arrangement is too complicated, and has not been adopted in India.

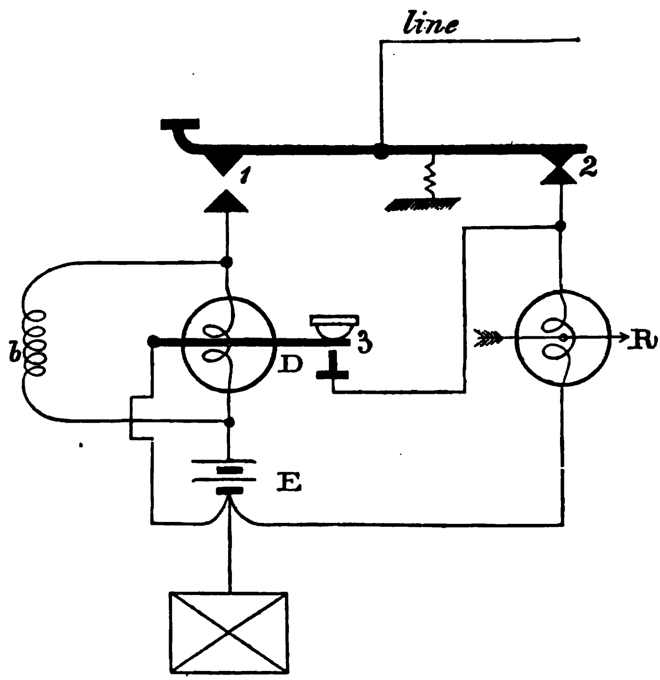
XIV. *Discharging Relay.*—Fig. 6 gives the diagram of this arrangement.

R is the receiving relay. }
D is the discharging relay. } Both Siemens'.

b is a coil of wire wound on a bobbin bifilarly, like a common resistance coil, which acts as a shunt to *D*, and can be made infinite by taking out a plug.

E is the signalling battery.

Fig. 6.



One of the local contacts of the discharging relay *D* is connected direct to earth, while the other local contact is in direct communication with that terminal of the receiving relay *R* which is in connection with the rest contact of the key, contact 2. Further, the discharging relay is connected up between contact 1 of the key and

the insulated pole of the signalling battery in such a manner that a sent current works the discharging relay —*i.e.*, moves the tongue to close contact 3. Thus, when closing contact 1, contact 3 will also be closed while contact 2 is open; and when the key is at rest, contact 2 is closed and contact 3 open. Hence there will be, during the movement of the key, a position of the tongue of the discharging relay when contacts 2 and 3 are both closed simultaneously, and therefore if the time during which these two contacts (2 and 3) last together can be made large enough, it is clear that the greatest part of the discharge of the line can pass through 2 and 3 to earth, so that the remainder of the discharge is too weak to affect the receiving relay when the key comes to rest. To prolong the simultaneous contacts 2 and 3, the shunt b is introduced. On opening contact 1, the induced magnetism in the iron core of D ceases. This cessation produces a current of the same sign in the closed circuit $(b + D)$ as the original sent current. Hence the magnetism in D must die out at a slower rate than it would without the shunt b. Thus the contact 3 is prolonged by the application of the shunt. In order to make this prolonging effect of the shunt a maximum, we must put

$$b = D\sqrt{\frac{L}{L+D}}\,{}^{*} \quad \dots \quad \dots \quad (27)$$

where L is the total circuit resistance of the line in question.

D the resistance of the discharging relay, and b the resistance of the shunt.

D, the resistance of the discharging relay, should be selected as small as possible, but large enough (sufficient

* *Journal of Asiatic Society of Bengal*, 1871, vol. xl. pt. ii. p. 78.

number of convolutions for the given space of the relay coils) to make it work with engineering safety by the sent current. As a part of the charge of the long line has to pass through D, and as, further, Siemens' relays are exceedingly sensitive instruments, the resistance D can be made so small that we may neglect it against L, when we have

$$b = D \quad \ldots \quad \ldots \quad \ldots \quad (28)$$

The magnitude of D itself we find can be made as low as 100 ohms.

Further, the prolonging effect of the shunt is quite sufficient to discharge the longest direct-worked line, even during the hot season when charge and discharge are at a maximum, and therefore an additional spring, connected with the tongue of the discharging relay, can be dispensed with. Such a spring is moreover objectionable, as it must have a certain play, however small, which must interfere with the sensitive adjustment of the discharging relay. The discharging relay has been introduced on all the main lines in India since 1871, at terminal stations as well as at translation stations, and has been found to answer the purpose fully. The discharging relay * with its small bobbin is fixed to a board with four terminals, and the whole is closed by a wooden box with a glass cover. These instruments are issued separately, and are then to be connected up in the office, according to the plan given in Fig. 6. On some of the new inkwriters the discharging arrangements are connected up directly, but it is preferable to have them separate.

* It was at first found that these discharging relays were often damaged by the wire breaking, which was attributed to lightning. Later on, however, it was established that lightning had nothing to do with it, but that the wire corroded from the combined action of damp air and the strong currents passing through the coils (electrolytic action), for since soaking the coils in the insulating mixture, by which the damp is kept out, no more cases have occurred.

Adjustment of the discharging relay.—The same rules which have been given for relays in general are equally applicable here. Put in the plug, *i.e.*, shunt the relay, and then send regular signals, and keep your ear close to the discharging relay, when it should work perfectly—this, by the sharp click of the tongue, can be easily discerned. A good ear will then observe that on making contact 1, contact 3 will be made simultaneously; while on opening contact 1, contact 3 will last somewhat longer than the making of contact 2. To get a good practical average position of the relay tongue, adjust first the relay as sensitively as it will work, afterwards as unsensitively as possible. Then keep the tongue in about the middle between these two limits. With a little practice this can be easily achieved.

XV. *D'Arlincourt's Discharging Arrangement.*—Fig. 7 represents the diagram.* The different instruments are shown in their position of repose, *i.e.*, when no signals pass.

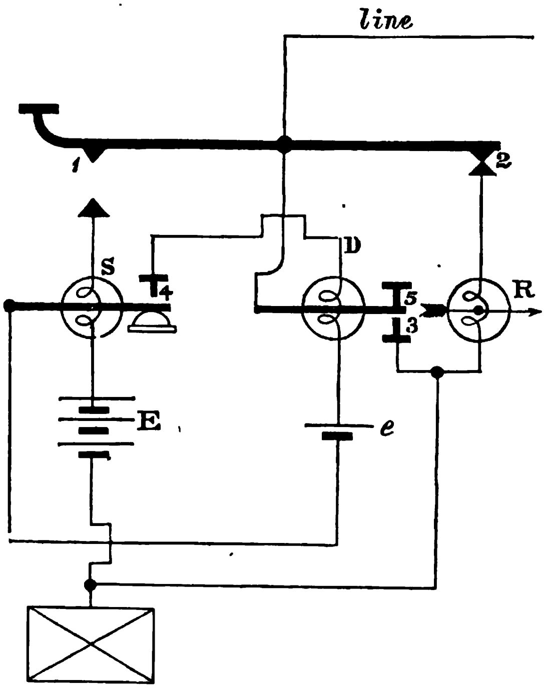
R is the receiving relay. } Both D'Arlincourt's.
D is the discharging relay. }
E the signalling battery.
e the local battery.

S any kind of electro-magnetic armature, inserted between the insulated pole of the signalling battery and the front contact of the key. The sent current works the instrument *S*, and closes contact 4, by which the circuit of the local battery *e* is completed through

* The mode of connecting up the discharging relay as shown in Fig. 7 is different from that actually used by D'Arlincourt, who connects the tongue of the discharging relay to contact 2 of the key. As the "flick" is almost instantaneous, contact 3 may in many cases be broken before contact 2 is made, and when therefore the line would have no chance of discharging itself. This fault has been eliminated by connecting the tongue to the body of the key.

D. Further, *D*, the discharging relay, is connected up in such a manner that the local current which passes through *D* when contact 4 is closed, exerts a force on the tongue of *D* of the same sign as its rest-force. In other words, when the local current passes through *D*, contact 5 is not opened, but, on the contrary, made tighter. The contact screw at 5 is, of course, insulated,

Fig. 7.



and acts only for limiting the play of the tongue. It is essential to notice that the relay tongue of *D* is connected with the body of the key, and *not* with its rest-contact, as was the case in the former discharging arrangement. Now, suppose that a signal is sent into the line. At the beginning of the signal when contact 1 is closed, contact 4 will also be closed, while contacts

3 and 5 remain as they are, *i.e.*, contact 5 keeps closed, it is only made somewhat tighter, and contact 3 remains open.

In this state the contacts remain so long as contact 1 lasts. But at the end of the sent-signal, when contact 1 is opened, contact 4 is also opened, and, consequently, the local current through *D* interrupted. Thus the magnetism in *D* ceases, producing in D'Arlincourt's relay, as has been explained before, a momentary force, which is invariably opposite to the one working the relay, in this case opposite to the force which closes contact 5 tighter. Consequently, if this momentary force is strong enough, contact 5 must be opened and contact 3 closed, after which the tongue returns to its position of rest, where it remains until the end of the next sent-signal.

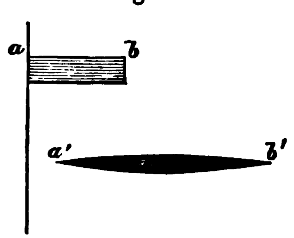
This complete oscillation of the tongue from 5 to 3 *and back* again to 5, when the local current at 4 is opened, and the sent-signal ceases, D'Arlincourt has called a *coup-de-fouet* (flick), and it is by this flick of the tongue against contact 3 that the discharge of the line is effected. As this flick is enormously rapid, contact 3 is made much before contact 2, which increases the chance of completely discharging the line after each signal sent. It will be clear that the instrument *S* and the local battery *e* can be dispensed with, by inserting *D* between the insulated pole of *E* and the front contact of the key. The object of D'Arlincourt's more complicated arrangement is to ensure the greater regularity of the action of the discharging relay, by rendering it independent of the variations of the sent current. This, however, appears to be an imaginary advantage, since *all* variations of the sent current are felt by the interposed instrument *S*, and, besides, as the sluggishness of *S*, especially in the opening of contact 4 when contact 1 ceases, cannot be small, it would be far better to dispense with *S*, and work *D* direct by the sent currents. This alteration

would only necessitate an increase of the resistance of the discharging relay.

XVI. *Electro-magnetic Shunt.*—It was observed on the long main lines that, although the relays in use had a range of not less than 20, still the speed of working was low, and the relays had to be constantly adjusted during the receipt of messages. It became, therefore, a matter of the utmost importance to discover and eliminate the cause of this irregularity of working; and, since the range of the relays was known to be considerably in excess of what was actually requisite to allow for the changes of strength in the signalling currents *due to variation in the insulation of the lines*, the source of this irregularity had to be sought for elsewhere.

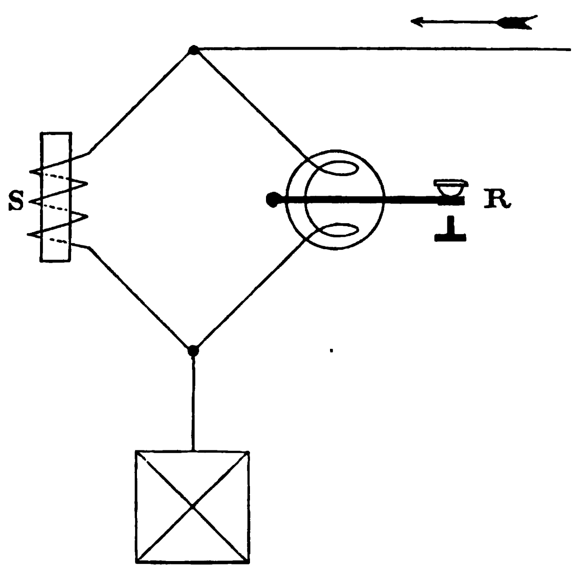
In Para. XII., the phenomenon of *charge* and *discharge* of telegraph lines, arising from their *electrostatic capacity*, have been explained, and their effect in modifying the speed and clearness of the received-signals shown; namely, that on account of *charge*, the received-signal begins later than the sent-signal, and, on account of *discharge*, the received-signal lasts longer than the sent-signal; and further, owing to the same causes, the received-signal, instead of beginning and ending abruptly, is initially at zero at the commencement of the sent-signal, gradually reaches a maximum as the line is fully charged, and finally, at the cessation of the sent-signal, gradually falls again to zero. Thus, if the sent-signal be represented by the sharply-defined mark *ab* (Fig. 8), the received-signal may be represented by the mark *a′b′*, beginning later, and tapering to a point at both ends.

Fig. 8.



This effect of the charge and discharge must, therefore, manifestly reduce the clearness of the received signals; and the more so in proportion as they are tapered out, or, in other words, on a long line, and when signalling up to the full carrying speed of the wire. To remedy this defect an electro-magnetic shunt was introduced.*

Fig. 9.



The action of the electro-magnetic shunt in neutralising the effects of the electro-static capacity of a line will

* Mr. W. P. Johnston, Asst. Supdt. Gov. Tels. in India, has suggested this method. The use of an electro-magnetic shunt in connection with the receiving instrument is recommended by Varley in his patent, No. 3453 of 1862; and I find that, in America, where the conditions of telegraphy approach those existing in India, shunts have been applied to the receivers (Bains's chemical) employed in connection with the high speed automatic transmitters. Mr. Edison uses an electro-magnetic shunt, while Mr. Little employs an electro-static shunt (condenser) with the same object, namely, of rendering the received signals more clear and regular.

be clear from the following:—At the beginning of a signal, the currents passing through the relay and shunt at the receiving station (see Fig. 9) are *increasing* quantities, and, therefore, extra currents are induced in the shunt and relay in *opposite* directions to the primary currents. But since the shunt, on account of its *mechanical arrangement*, has a greater magnet-inductive capacity than the relay, the extra-current due to the shunt is greater than that produced by the relay, and the excess current from the shunt flows through the relay in a direction so as to *augment* the received signalling current. Hence the received signal commences more abruptly than it would have done without the shunt.

Again, at the end of a signal, the currents passing through the relay and shunt are *decreasing* quantities, and, therefore, extra currents are induced in the shunt and relay in the *same* direction as the primary current. As before, the extra current due to the shunt is greater than that due to the relay, and, therefore, the excess current from the shunt will flow through the relay in a direction so as to *oppose* the received current, and neutralise the discharge of the line. Hence the received signal will end more abruptly than it would have done without the shunt. It will be seen, therefore, that the action of the shunt is to render the signal more clearly defined, both at its beginning and at its end. It is manifest that, in order that the shunt may have any useful action in this respect, its magneto-inductive capacity must invariably be greater than that of the relay. In practice it is made *double* that of the relay, which is found sufficient, and leaves a margin for accurate adjustment. Further, to act to the greatest advantage, the resistance of the shunt must clearly be equal to that of the relay. The inductive capacity of the shunt can be easily regulated by means of a wedge-shaped armature.

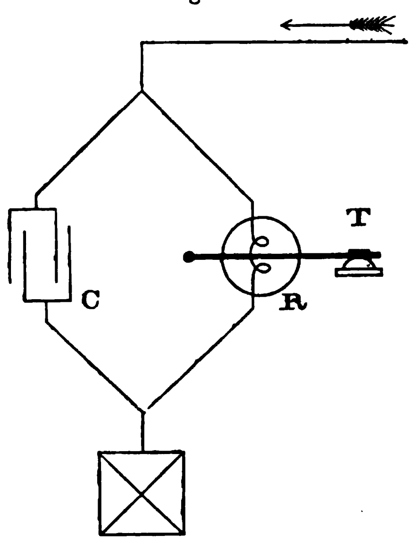
When the thick end of the wedge is touching the cores, the action is greatest, and as it is gradually withdrawn, the action is progressively diminished. When once the magneto-inductive capacity of the shunt has been adjusted to suit the receiving instrument to which it is applied, it will only require re-adjustment when the inductive capacity of the line varies. For instance, during the rains, when the discharges are small, the action of the shunt will have to be diminished; while, during the dry weather, when the insulation is high, it will have to be increased. It must be added, that the electro-magnetic shunt presents another advantage, in so much as it counteracts the effects of *extra currents*, and of any *residual magnetism* due to coercive force in the receiving instrument. The shunt must not be placed too near the receiving instrument, as it may interfere with its action by its direct magnetic influence. It will be clear that, if we join a Siemens' relay armed with an electro-magnetic shunt (always of greater magneto-inductive capacity than the relay) on short circuit, and adjust the tongue by means of the micrometer-screw, so that it rests against the local contact screw, and permanently closes the local circuit, then when we send a positive current through the relay in the working direction no motion of the tongue will take place, but the pressure against the local contact screw will be temporarily increased. At the moment, however, of interrupting the current, the tongue will, owing to the passage of the extra current from the shunt through the relay in the non-working direction, fly over and remain momentarily against the rest stop, and then return to the local contact screw again. This oscillation of the tongue is a phenomenon precisely analogous to the *coup-de-fouet* or flick in D'Arlincourt's relay, described before.

XVII. *Electro-static Shunt.*—When experimenting with the electro-magnetic shunt, an endeavour was made to imitate the action of a line by joining a condenser across between the two terminals of the relay. Instead, however, of such an arrangement retarding and prolonging the signals as was expected, it was found to act altogether in the opposite direction, *i.e.*, the signals were neither perceptibly retarded nor prolonged; and the relay, when suitably adjusted, gave a *flick*, just as in D'Arlincourt's relay, or as if an electro-magnetic shunt had been employed. The relay under experiment was a Siemens' polarised relay with a resistance of 3600 ohms. It was ascertained that a capacity of about 2 M. F. produced a very perceptible *flick* with 10 Minottos through no additional external resistance; and it was further found that, when the capacity of the condenser was increased to 4 M. F., or decreased to 1 M. F., a *flick* of the same force could only be produced by using a stronger primary current. These experiments, although rough and scarcely better than qualitative, proved nevertheless that a condenser may be substituted for the electro-magnetic shunt, and that for any given relay there would appear to be a certain capacity of the condenser which produces the greatest *flick* for a given strength of current. The action of the condenser when employed as a shunt to the receiving relay may be explained as follows (see Fig. 10):—

At the beginning of the signal, and so long as the arriving current remains an *increasing quantity* (*i.e.*, until it has reached its maximum strength), almost the whole of the current goes to charge the condenser *C*, and very little passes through the relay *R*. The effective current passing through the relay *R* is further diminished by the inverse extra current of magnetisation, which tends to neutralise it. The moment, however,

the arriving current reaches its maximum strength, and the condenser becomes fully charged, no more current can pass into the condenser *C*, and the full strength of the arriving current is thrown through the relay *R*, producing a signal with a clearly-defined beginning. The action at the end of the signal being secondary, is somewhat more difficult to understand. From the moment the arriving current commences to decrease in strength, the condenser *C* discharges itself, sending a positive cur-

Fig. 10.



rent through the relay *R* in the working direction; but the extra current of de-magnetisation arrests this current, and, owing to its great power (on account of the *mechanical arrangement*, *i.e.*, number of convolutions), neutralises the remaining original charge in the condenser, and finally charges it, in an almost infinitesimal time, in the opposite direction; after this the condenser (now charged in the reverse direction) discharges itself, sending a positive current through the relay in the non-work-

ing direction. This current neutralises the discharge of the line, interrupts the signal, and gives it therefore a clearly-defined end. The practical question with regard to the two methods (electro-magnetic and electro-static) is, of course, which will give the strongest *flick* for the least cost with a given primary current; and, so far as we at present know, this must be decided in favour of the electro-magnetic shunt.

XVIII. *Experience with Siemens' Relay.*—Many years' experience in the practical working of this relay has shown that the relay carriage was liable to get out of order by constant use. The carriage became shaky, and a stable adjustment therefore impossible, interfering to a great extent with the satisfactory working of the relay. Another objection to the use of the carriage was that while the end of the tongue necessarily moved along the arc of a circle, the contacts, fixed to the carriage, moved in the tangent to that circle. The consequence of this was that when the play of the tongue was made small, and the carriage was moved to a considerable distance from its medial position in either direction, the end of the tongue became jammed in, injuring itself and the two contacts, and interfering with a free and wide-ranged adjustment of the relay. The mode of adjustment now adopted is taken from the construction of the D'Arlincourt relay. The two contacts, *rest* and *local*, are fixed rigidly with reference to the neutral line of the relay, only their distance from each other, *i.e.*, the play of the tongue, can still be altered in the usual manner. The actual adjustment is made by an *iron* micrometer-screw, which can be screwed *in* and *out* of one of the two shoes, which are still left adjustable in the old way. In this manner nothing else is altered by adjustment but the quantity of iron acting on one side of the tongue.

Hence the relay can be adjusted stably and much more sensitively.

The tongue itself has been made shorter and lighter, and by this means the sensitiveness of the relay has also been increased. Further, by connecting across the relay an electro-magnetic shunt, or an electro-static shunt, the *rest* force of the relay, instead of being constant, or, still worse, decreasing, with increasing working current, is temporarily augmented at the end of each signal, as in D'Arlincourt's relay, and by it the regular working of the relay greatly enhanced.

XIX. *Experience with D'Arlincourt's Relay.*—The reports of the officers, under whose charge these instruments have worked, are all favourable. They state that when once the relays have been properly adjusted, further adjustment is not required for a long time. It has further been found that *e*, the local battery, must consist of at least eight Minotto local cells, in order to produce the *coup-de-fouet* with sufficient strength to discharge the line effectually. That the D'Arlincourt relay, when once properly adjusted, must require scarcely any further adjustment, follows from its great range, which, beginning with a given minimum force, must be almost infinite; because the force which brings the tongue back to its position of rest, increases with the force which works the relay. Hence a sticking of the relay by strong currents becomes impossible. A fresh adjustment of the relay is only required, when the line becomes so low in insulation that the force which has to work the relay is smaller than the minimum force for which the relay was at first adjusted. Hence it is advisable to adjust the relay from the beginning, when it is first put up, as sensitively as the construction of the instrument will allow. There is, however, a practical limit for such sensitive

adjustment. For relay, sounder or breaker of local circuit, and discharging relay, are all on the same board, and consequently the working of the breaker, which, as stated before, must be done with a sufficiently great force, may close the line relay by mechanical shaking. In fact, our experience goes to prove that the principle of the relay is perfect, but that its mechanical construction and arrangement admit of improvement.

XX. *Receivers.*—There are two kinds in use in India, viz., *the sounder* and *the inkwriter.* The inkwriter is only used on the main lines for international messages: according to Articles 3 and 23 of the Rome Convention, the employment of recording instruments is compulsory. But even where an inkwriter is employed, the message is *not* copied from the tape, but is read invariably from the sound, which the armature of the inkwriter produces by striking the limiting screws. In fact the tape is only made to run for the purpose of record, and then only when an international message is received. All inland messages are read from sound without keeping a record on tape.

XXI. *The Sounder.*—There are many different patterns of sounders in use in India, but it would be waste of time and space to describe them all in detail, since their construction is necessarily based on one and the same principle. A sounder may consist of any suitable form of electro-magnet, the poles of which are in close proximity to a moveable soft-iron armature. The armature is generally suspended and balanced on a horizontal axis, and is kept in its position of rest by an adjustable spring.

Thus when a current passes through the coils of the electro-magnet the armature is attracted against the

force of this spring, which, when the current ceases, pulls the armature back again to its position of rest. To limit the play of the armature, and also to vary its maximum and minimum distance from the poles of the electro-magnet conveniently, two adjustable screws are employed which, in the case of translation, serve in addition as electrical contacts. The striking of the armature against the screws produces sounds, which, when signalling the Morse alphabet, follow in short or longer intervals (points and bars), and from it an experienced ear is able to recognise the letters transmitted.

Reading by sound.—Any signaller, who at first is taught to read from the tape of a Morse instrument, is soon able to dispense with this mode of receiving, and to write down the message from the succession of sounds, which the armature produces on striking the limiting screws. Each signal received is enclosed by two distinct separate sounds. If the open circuit is used, the beginning of each signal is indicated by the *down-stroke-sound*, and the end of each signal by the *up-stroke-sound.* If the closed circuit is in force, the reverse takes place. A point is produced by these two sounds following each other in a comparatively short interval of time. A bar is produced by this interval of time being longer; according to the rules of the Morse alphabet, this interval of time should be three times as long as for a point. The space between any two signals, which is to be of the same length as that of a point, is distinguished by the receiving signaller in two ways:—

1*st.* By his own knowledge that after each signal a space *has* to follow.

2*d.* By the *down-stroke* sound being different in nature from the *up-stroke* sound; for the two sounds are produced by the same body hitting with different force two different bodies. Thus even if we wished to

make these two sounds the same, *i.e.*, equal in form, intensity, duration, and pitch, it could only be done with great difficulty. Besides, we do not want equality, but rather inequality of these two sounds, since then the space is not only distinguished from the point mentally, by the signaller's knowledge of the alphabet, but also physically.

For instance we will designate the *down-stroke-sound* 1, the *up-stroke-sound* 2. Then for *open circuit*, the signals are produced in the following order:—

$$1 \underbrace{\qquad\quad}_{\text{point}} 2 \underbrace{\qquad\quad}_{\text{space}} 1 \underbrace{\qquad\qquad\qquad\qquad\qquad}_{\text{bar}} 2 \underbrace{\qquad\quad}_{\text{space}} \ldots \text{ etc.}$$

For the closed circuit by—

$$2 \underbrace{\qquad\quad}_{\text{point}} 1 \underbrace{\qquad\quad}_{\text{space}} 2 \underbrace{\qquad\qquad\qquad\qquad\qquad}_{\text{bar}} 1 \underbrace{\qquad\quad}_{\text{space}} \ldots \text{ etc.}$$

Hence the space in open circuit is situated between the sounds 2 and 1, while a point is situated between the sounds 1 and 2; and in the closed circuit it is the reverse. Therefore a difference in the two sounds 1 and 2 must naturally assist the signaller in reading.

Reading from sound is undoubtedly more difficult than reading from tape, but when once known and continually practised it becomes a second language to the signaller, and he will no more forget it than he will his mother tongue. The success of reading by sound depends on two essentially different conditions, viz., on the *sending and receiving signallers*, and on the efficiency of the sounder.

Sending and receiving signallers.—A signaller should send with uniform speed, and should keep the intervals of time for points, spaces, and bars in constant proportion, and independent of the speed of signalling.

This, of course, can only be attained by practice, and by invariably beginning, when teaching signallers, with tape instruments, that the result of sending may be recorded and examined. It has been pointed out in circulars how often traffic is delayed by sending signallers becoming impatient and not fulfilling the conditions as laid down. A sending signaller should invariably, without being told, alter his speed of sending according to the capacity of the receiving signaller, since it is not always possible to post two signallers of equal practical ability on the two ends of a line. The maximum number of words which can be transmitted by *hand signalling* is no more than thirty-five five-letter words per minute. A good signaller moves only his wrist, not his whole arm, as beginners generally do. It is quite unnecessary to use a large force for pressing the key down, for the distant receiving signaller will not get the message better by this being done. A very good signaller can receive by sound as fast as any other can send. As a rule signallers can send faster than they receive, especially beginners. With some of the signallers it has become a habit to adjust permanently the relay while receiving, even if such adjustment is by no means required. This is *not* allowed.

Efficiency of sounder.—The working efficiency of a sounder depends clearly on its construction and adjustment. The construction is fixed, and we have therefore nothing to do with it here. The proper adjustment, however, is not given, but is essential; although sounders will work with very different adjustments—which in fact they ought to do if the construction is good—there is, nevertheless, *one* adjustment, which is the *best.* It represents almost a definite problem. This shall be treated of in detail.

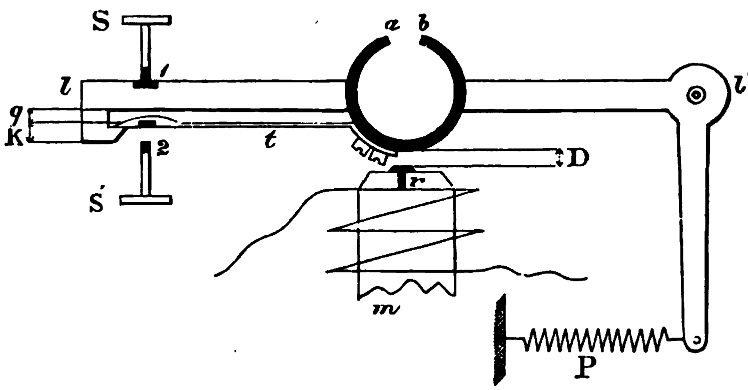
Adjustment of the sounder.—In order to explain conveniently and clearly the best adjustment of the sounder,

Fig. 11 gives the diagram of its principal adjustable parts, regardless of the actual mechanical construction of the instrument.

S, *S'*, are the two limiting screws which are made adjustable. These screws are platinum tipped, as they also act as electrical contacts when the sounder is used in translation. Each of the two limiting screws can be rigidly fixed, which is generally and best done by a jam-nut.

P is a spring, generally a spiral spring, the strength

Fig. 11.



of which can be regulated to requirements in the ordinary manner.

To the lever *ll'*, which turns on a horizontal axis (*l'*), is fixed the soft-iron armature *ab*.

m is the electro-magnet, *r* is a small brass rivet placed in the middle of each iron core of the electro-magnet. This rivet serves to prevent the armature *ab* from actually touching the iron cores when attracted. The little rivet protrudes only very slightly, scarcely more than the thickness of common writing paper.

t is the translation spring, made of best steel, and

yellow or blue tempered. On the side of the screw S' the translation spring carries a platinum contact.

When no current passes through the helix of m, the spring P presses the lever ll' against the screw S, and closes contact 1.

When a current passes through the helix of m, the armature ab is attracted by m, against the force P, by which contact 1 is opened and contact 2 closed.

When the current in the helix ceases, the spring P brings the lever back to its original position of rest.

The screws S and S' are insulated from each other, and from every other part of the instrument.

q is the play of the translation spring.

k is the contact play, and consequently $q + k$ the play of the lever. The distance between the lowest point of the armature ab and the upper surface of the rivet r we will call D when the armature is at rest, and d when attracted by m.

Ascertain whether the lever is quite free to move; sometimes the axle l' offers too much friction. If the axle, as in Siemens' reduced Morse-sounder, is pivoted against the points of two adjustable screws, a freer movement can be easily obtained by lifting the jam-nuts and screwing out the screws. In the other pattern the clamping screws may be lifted somewhat, and, if necessary, a small quantity of watch oil employed. After this, see that the spring P is in order, and can be easily regulated by its screw. Taking hold of this screw, and elongating the spring P, the square stem to which the spring is attached, and which moves in a hollow ebonite cylinder, should come out easily; and when letting go the screw, the stem should snap back again to it original position. The armature ab, when at rest, as well as when attracted, should be parallel with the surface of the cores. Sometimes this is not the case, and a slight bending of the armature will correct the defect.

Now adjust first the limiting screw S' to such a height that $d > o$, or that the armature does not actually touch the rivet r when attracted. This is required in order to make the down-stroke-sound clear, and further, to avoid shaking of the instrument. But otherwise d should be made as small as practicable. The proper d can be found as follows:—

Take a piece of common writing paper, place it between armature and electro-magnet, and press the armature down either by hand or electrically; the latter is preferable. Then, while keeping the armature pressed down, adjust S' so long until the paper can be moved from between armature and electro-magnet with some slight friction. Then clamp up S' by its jam-nut, and do not touch it again.

The play q, it will be seen, cannot be altered. It is made for all the sounders the same, about 0·01 of an inch. As great care is now bestowed on the manufacture of these translation springs, they keep constant in form, and therefore q will also keep constant. The play q of the translation spring has been made so small as not to interfere with our quickest working speed (thirty-five words per minute). It has been frequently observed that these translation springs have been made rigid by means of a small piece of wood being pushed between the play q, or by tying the spring to the lever, &c. This is *not* allowed, even in offices where the sounder is not generally used for translating. At present the play of the translation spring is made so small that it cannot interfere with the clearness of the sound. When the lever is at rest, the translation spring should rest on the little nose of the lever. Now, the distance D, or what is the same, the play k, is to be adjusted by the screw S. The larger D is made for any given P, the more force must be exerted by m on ab to attract the armature,

and the slower the armature will act; while the sounds produced will evidently be loudest. On account of the translation spring having a given play q, we know that $D > q + d$ invariably, as otherwise the contact 2 could not open out when the upstroke of the lever takes place. Hence there is a certain D which is quite large enough to open with certainty the contact 2, and to produce sufficiently loud sounds, and also small enough to allow the lever to follow quickly, and to make the attraction between m and ab for a given current passing through the helices sufficiently large. This will then enable us to adjust the spring P as strong as possible. Whence it follows that the down and up strokes are both made with great decision. This best D being highly individual, can only be found by experiment. After having S adjusted, fix it rigidly by its jam-nut, and do not touch it again.

The spring P is now to be adjusted. This is best done by working the sounder electrically, and then making the spring weak enough that the downstroke is made with decision, and strong enough that the upstroke follows also with decision and closes contact 1 with sufficient pressure. The following more definite method will be found to lead to a good adjustment of the spring :—

Work the sounder electrically and tighten the spring until the magnet is unable to attract the armature, mark the position of the screw on the stem. Now loosen the spring until the armature falls on the electro-magnet by its own weight, mark this second position of the screw. Then tighten the screw to about the middle between the two marked limits. Thus we have the following general rules for adjusting a sounder, which should be followed in the order given :—

1. Best d by adjusting S'. The smaller d can be

made, without the attracted armature touching the rivet or electro-magnet, the better the adjustment will be, under all circumstances.

2. Best D, or which is the same, *best* k by adjusting S with respect to clear sounds and rapid working of the lever. This adjustment must always be somewhat indefinite, since to a certain extent it will depend on what a signaller calls *a clear sound.*
3. Best strength of the spring P; this adjustment is quite definite if the average strength of P is used as is explained before.
4. After a good constructed sounder has been once properly adjusted, further adjustment of the screws S and S' should not be any more required; for the translation spring keeps constant in form. Any alteration which may go on in the friction of the lever or in the force which attracts the armature (strength of local current), can always be compensated by a small appropriate adjustment of P. It is essential that the jam-nuts which fix the screws S and S' rigidly to their respective pillars, should be securely tightened.

Sounder coils.—The two bobbins of the sounder are filled uniformly with insulated copper-wire of highest procurable conductivity. The coiling of the wire is always done in the same sense; either they are wound as left spirals or as right spirals; we use always left spirals. The number of convolutions of wire to fill up the bobbin is counted, and as all sounder bobbins are of equal size and the wire used is of equal thickness, if the winding has been done carefully, all the bobbins should show the same number of convolutions. Thus the number of convolutions controls the coiling, while the

measurement of the resistance controls the conductivity of the wire. The number of convolutions and the resistance are marked on each bobbin. In the resistance we do not allow more difference than about 16 per cent.; in the number of convolutions $\sqrt{16} = 4$ per cent. No paper is allowed between the layers. The two coils are connected up successively, so that, when a current passes through the wire, the two soft iron cores are formed into a horse shoe electromagnet. The connecting point between the two coils is placed conveniently in order to allow a separate measurement of the resistance of each, in case it should be required in the future.

The sounder coils issued previously to 1868 had generally a resistance of between 2 and 10 ohms. Since the introduction of the Minotto cell, however, which, by its nature, has a comparatively high resistance, this resistance of the sounder coils was found to be too low, *i.e.*, the local battery required to produce the necessary magnetism in the cores became inconveniently large in surface. Besides, there is no reason why bobbins of equal size and working the same kind of instrument should be filled with wire of different diameters, and as further it is evidently cheaper and more convenient to produce magnetism by weaker currents and more convolutions than by stronger currents and less convolutions—the resistance of the coils was raised to about 30 B. A. U., and made the same for all bobbins used for sounders. Such coils, each of about 15 B. A. U. resistance, when a current of four local Minottos, connected up successively, passes through them (each local Minotto with an average internal resistance of about 7·5 B. A. U.) produce sufficient magnetism in the cores to attract the armature with engineering safety. Hence any new sounder issued has now these high resistance coils, and

those issued formerly have been gradually replaced by others with high resistance. Thus, the local circuits in India are worked by an average current of 72 milli-oersteds, which decomposes 0·089737 milli-grammes of sulphate of copper, per second, in each cell. The total work done in a single local circuit, one sounder worked by 4 local Minottos, is ·06986 centimetre-grammes per second. Half of this energy is used in producing magnetism, a great part of which is made use of for attracting the soft iron armature. When the sounder is adjusted in the manner described, minimum *d*, the attracted armature can carry about 334 grammes against gravity.

These data can be calculated from the following formulæ:—

$$c = \frac{E}{s+b} \text{ oersteds.}$$

$$n = 0{\cdot}00001\ a\ c \text{ grammes per second.}$$

$$W = 10192\ c^2\ (s+b) \text{ centimetre-grammes per second.}$$

c is the strength of the current in oersteds per second.

n the weight of metal in grammes, deposited from the solution of the galvanic cell by the current c in one second.

W the work done in one second by the current c in the circuit of total resistance $s + b$.

E the E. M. F. in volts.

s the electrical resistance of the sounder in ohms.

b the internal resistance of the battery in ohms.

a the equivalent weight of the metal deposited when that of hydrogen is taken as unity.

In our special case we have therefore—

$$E = 4 \text{ Minottos} = 4 \times 1{\cdot}079 = 4{\cdot}316 \text{ volts.}$$

$$s = b = 30 \text{ ohms.}$$

$$a = 31{\cdot}75 \text{ for copper.}$$

From n, the weight of the copper, we get the weight of

sulphate of copper by multiplying n with the molecular weight of sulphate of copper, and dividing by 63·5. The chemical formula for hydrated sulphate of copper is $CuSO_4$, $5H_2O$, and the atomic weight of the single elements are—

$$\begin{aligned} Cu &= 63{\cdot}5 \\ S &= 32{\cdot}0 \\ O_4 + O_5 &= 144{\cdot}0 \\ H_{10} &= 10{\cdot}0 \\ \hline \text{Total,}\ & \ 249{\cdot}5 \end{aligned}$$

The carrying weight of the attracted armature, 334 grammes, has been found from numerous experiments, and represents an average value.

Tests of the Sounder.—Resistance: to be measured, corrected to 80° F., and marked on a brass label attached to the base board. It should be about 30 ohms (not greater than 35 or less than 25 ohms). The resistances of the two coils should be equal.

Insulation: between the lever and S', with the lever at rest; between the lever and S, with the lever depressed; and between the lever and the coils.

Conduction: between the lever and S, with the lever at rest; and between the lever and S' with the lever depressed.

Mechanical Execution: The bobbins should be wound so that when a current flows through the coils the one end of the horse-shoe electromagnet becomes a north pole, and the other a south pole. The anticontact should project 0·12 mm. from the core. The space q between the lever and the translation spring should be 0·12 mm. The translation spring should be well-tempered, exactly centred over the screw S', and rest against the nose K when the instrument is in repose. The axes of the screws $S\,S'$ should be vertical, and they

should be fixed firmly when their jamnuts are tightened. The lever should move without undue friction, and have a slight lateral play in its bearings. When necessary the bearings should be oiled with a little oil. The armature should be at right angles to the lever, horizontal, and equidistant from the ends of the two cores. On drawing out the antagonistic spring, and then releasing it, it should snap back into its original position.

XXII. *Portable Sounder.*—This instrument has been designed for the purpose of being able to cut in conveniently at any point of a telegraph line, and communicate with the nearest telegraph station. Formerly, before the system of localising faults had been introduced, the greatest use was made of these instruments by the signallers who had to proceed along the line, in case of imperfect working or interruption, to discover the fault and restore communication. At present it is, however, very rarely used for this purpose, but is mostly applied by inspecting officers and working parties to keep up communication with the nearest telegraph office.

The construction of the Portable Sounder is based on the principle of the polarised relay. It is, in fact, a polarised Sounder, the signals being read direct from the tongue. Further explanation is therefore not required. Key and sounder are enclosed in a strong wooden box measuring 12·5 × 10·6 × 10·6 cm. The resistance of the sounder coils is about 500 ohms (250 to each coil). The instrument has three terminals marked *L*, *C*, and *Z*, to which line, copper, and zinc of the signalling battery are respectively joined. The battery used for signalling is the *portable battery* described on page 59. Since the introduction of some improvements, especially in the mechanical construction of the instrument, it has become very perfect, and fully answers its purpose. The

portable sounder can be easily adjusted to work with 2 milli-oersteds, and as the currents used for signalling on the lines are about four times stronger, the instrument, when in good order, always functions well. It is not required to carry a small copper earth plate, but the earth can be conveniently formed by any iron telegraph post, if the ordinary precaution, of cleaning and twisting the wire tightly, be taken. The earth wire is best connected to the zinc pole of the portable battery. It has been often observed that these useful instruments have been badly treated. When not in use, keep the box always closed and fix the tongue between the two adjustable screws. Oil the hinges of the box; keep the contact point of the key clean; keep the instrument in a dry place, and when travelling protect it from rain. There is no reason why these instruments should not be in quite as perfect order as any other telegraph instrument in an office. The special tests need not be given.

XXIII. *Ink-writers.**—These instruments print the message in Morse characters with a peculiar kind of ink on a paper tape running out at a uniform speed. The tape is driven either by a *weight* or *spring* clockwork.

* The ink-writer must be considered a development of the original Morse apparatus, by which the message was printed in relief on a paper tape. This simple method of recording the signals, it was soon found, however, had three distinct, and not inconsiderable, disadvantages. In the first place, if the light is not quite perfect, or better, not shining at the proper angle on the relief signals, the message is difficult to read; secondly, the force required to emboss the signals distinctly on sufficiently thick paper is found to be larger than can be conveniently produced, even by a strong local battery; and lastly, these impressions in the paper are not durable, and can be easily taken out, which makes this method of recording uncertain. Hence suggestions were made to eliminate these defects, but none were found to be practicable until in 1854 Th. John, a telegraph clerk in Austria, conceived the very practical idea of applying a small revolving wheel with its edge dipping in ink specially prepared for the purpose. This is the method now in use.

When no signal is passing, the paper runs out without a mark on it; but when a signal is received a small revolving wheel, the edge of which is kept permanently inked, presses against the tape, and produces a straight line on the paper. This line, if short, represents a dot; if long, a dash. The printing duty is generally performed by a separate electromagnet worked by a local battery, the circuit of which is closed by the line current by means of a relay in the usual manner. In some instruments the printing duty is performed directly by the line current, as for instance in Siemens' polarised direct-working ink-recorder.

According to different requirements, and to the different objects of the inventors (to procure certain advantages in the working of the instruments), ink-writers have received a great variety of special constructions, though they are all based on the same general principle mentioned above.

In India the ink-writers in use are those of Siemens' construction, with a spring clockwork.

The relay is separate from the electromagnet, which is worked by a local battery, and exerts the force for printing.

These instruments are so well known that a drawing and detailed description appear unnecessary. Special attention will, however, be paid to the adjustment and maintenance of these instruments.

Formerly Siemens' ink-writers were fitted up on a board, together with a relay, galvanoscope, key, &c., but the plan of mounting several apparatus on the same board being objectionable, both economically and electrically, they are now isolated.

The ink-writer itself may be considered to consist of two parts, the *electrical* and the *mechanical*. With reference to the electrical part, further remarks are scarcely

required, as the electromagnet, worked by a local battery, and attracting an iron armature, is essentially the same as the sounder explained before. Our sole attention may therefore be given to the mechanical part of the ink-writer, which requires to be looked after in order to keep the instrument efficiently functioning.

The clockwork is enclosed in a brass case, and consists of a certain number of toothed wheels in order to get, on the one hand, from a given wound up spiral spring the required comparatively slow motion with which the paper tape has to run out; and, on the other hand, the comparatively high speed for the small governor (fly) which has to keep the speed of the tape uniform within certain practical limits. The axles of the wheels run on steel journals, bearings for which are afforded by the two largest parallel plates of which the brass case is formed. The holes, in which the axles run, are bored through the plates, and on the outside of each plate these holes are countersunk for the purpose of holding the oil. Each bearing is covered on the outside with a thin brass plate, which turns about one point on a screw, by means of which it can be tightened up.

These plates must always be kept over the holes, and only opened out when oiling the bearings.

A very important point for the regular working of any clockwork is to keep it free from dust. Hence the case enclosing the clockwork should never be opened unless absolutely necessary. To prevent dust and damp air from entering the clockwork, all the joints are hermetically closed up by putting paper between every two metal plates; and when an axle protrudes outside the brass case, the hole is closed up from inside by a velvet washer. In some of the ink-writers the paper wheel is carried by a support screwed on to the case. If it should be required to temporarily remove the paper wheel, the

screw holding the support should invariably be replaced. In fact, care should be taken that no fresh air be allowed to enter the clockwork, in order to prevent the steel and iron parts from rusting, and the bearings and wheels from becoming clogged with dust and fibre.

To wind up the clockwork the key has generally to be turned from *left* to *right*. By turning the key in the opposite direction it unscrews, and can be taken off.

The clockwork, when in good order, runs down in about half-an-hour. The receiving signaller should keep the spring wound up, and never allow the clockwork to run out.

With each instrument a spare spring is generally issued, tightly wound up, and tied together by a strong piece of wire. It may happen that the spring in use breaks, when it will be necessary to replace it by the spare spring, and as this is an operation by no means easy to perform, the following special instructions are given:—

Instructions for putting in a new spring.

Fig. 12 gives the view of the spring drum as seen from the side opposite to the key.

Fig. 12.

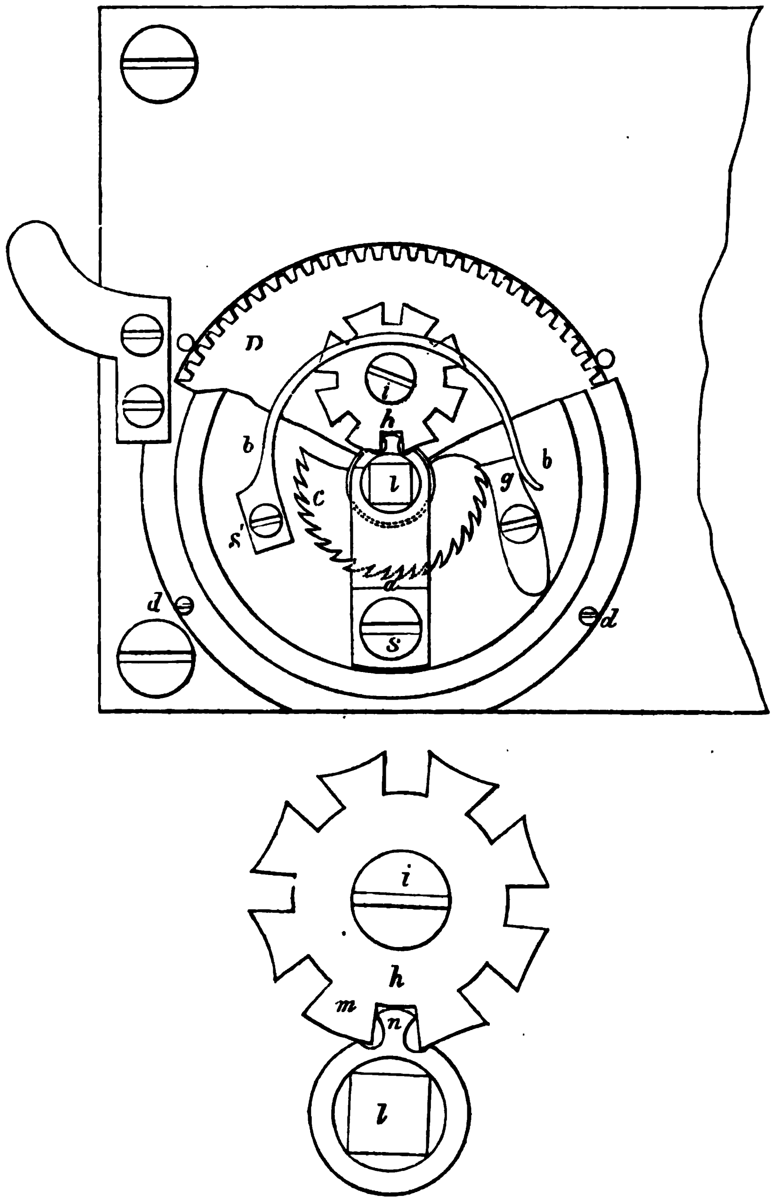
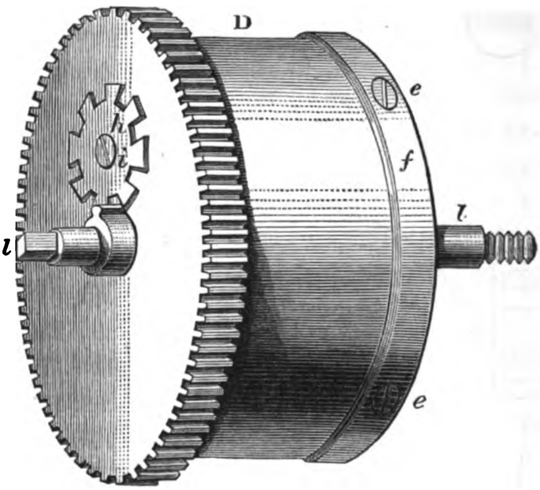


Fig. 13 represents a perspective view of the spring drum.

Fig. 13.



Let the clockwork run down, remove the bracket *a* by taking out the screw *s*, remove the steel spring *bb* by taking out the screw *s′*, and then take out the ratchet wheel *c*; the pawl *g* remains fixed to the plate. Now remove the covering plate which is fastened by the four screws *d*, and the drum *D* containing the spring can be taken out. Open the drum *D* by taking out the screws *e*, and remove the drum head *f*, when the spring will be exposed and can be examined.

If it is necessary to remove the spring, it can be taken out as follows: Take hold of the centre turn of the spring with a pair of flat pliers, and gradually pull out the spring. Then remove the stop-wheel *h* by unscrewing *i*.

The new spring, tightly wound up and tied together by a piece of wire, is now placed in the drum *D* in such a manner that the spring winds up when the key is turned from left to right. Cut the wire which keeps the spring together, when the spring will assume its proper

position in the drum. During this operation the drum must be held firmly in order to prevent the spring doing any damage. Turn the key from left to right, and the outer end of the spring, by means of a punched hole, will attach itself to a catcher fixed to the inner wall of the drum. The inner end of the spring will eventually fasten itself by means of a punched hole to the catcher fixed to the axle *l*. The difficulty is to fix the outer end of the spring to its catch. This is best done by placing the spring, before cutting the wire, in such a position that when the spring extends, after cutting the wire, the hole *must* pass the catch. Now take firm hold of the drum (the best way is to fix the drum in a vice), put in the key, and wind the spring up to about 1½ turn. While keeping the spring in this partly wound-up state, the stop-wheel *h* is replaced in such a manner that the convex tooth *m* presses against the shoulder of the stop finger *n*. Thus the spring can never run down entirely, and by this means the ends are kept permanently fixed to their respective catches. Some fine watch oil* should then be put on the exposed edge of the spring, and the drum head *f* fastened by its screws. This concludes the operation of putting in the new spring.

The drum *D* is now to be placed in the instrument. Push in the drum, and fasten the covering by the screws *d*, then replace the ratchet wheel *c*, and screw on the bracket *a*. After this fix the steel spring *bb*. This

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* Pivots and bearings of Telegraph instruments should only be oiled with *finest watch oil*, which is an animal oil (neat's foot oil), and *not* with any vegetable or mineral oils procurable in this country. Olive or salad oil is very bad, because it corrodes iron and steel; cocoanut and castor oil are also bad, because they are too sticky, and generally not pure enough. Each office should keep a small bottle of *watch oil* which, if not wasted, will last even in the largest office for more than ten years. Do not use a feather for taking out the oil, but fix a thin steel wire to the cork. This steel wire carries just enough oil required for any bearing.

spring must press with its free end with sufficient force against the pawl g, in order to force it into the teeth of the ratchet wheel c. Now the clockwork is ready for winding up.*

Fly-wheel.—At the bottom of the case a lever protrudes which, inside the case, carries a small bent brass spring. This spring can be made to rest against a small collar fixed rigidly to the axis of the fly-wheel. If the lever is pushed to the left, the collar is freed from the spring, and the clockwork starts; but if pushed to the right, the spring presses against the collar, and the clockwork stops. It may happen that the little spring loses its form, *i.e.*, that either it always touches the collar, or not at all. It should then be re-bent to its proper form, which can be easily done. The fly-wheel which regulates and reduces the speed of the clockwork is kept in its position of rest by a small spiral steel spring. It is requisite that the length of this spiral spring be adjusted in such a manner that, when the fly-wheel is at rest, the spring suffers neither tension nor compression; otherwise the clockwork will not start regularly, but with a jump. The clockwork being once for all properly adjusted, and being closed up and protected against injury, should keep in working order, except an accident happen. The bearings of the different axles can be oiled from outside without opening the brass case.

The paper wheel—In most of the ink-writers the paper wheel moves in a vertical plane on a horizontal axis, the bearings of which are formed by a vertical stand screwed on to the top of the brass case containing

* The whole operation described above requires considerable practice; and it appears better to send with each instrument a complete spare drum, instead of only a spare spring. If, for instance, by accident the wire which holds the spare spring together should break, it is exceedingly difficult to wind the spring up again without having the tools for it.

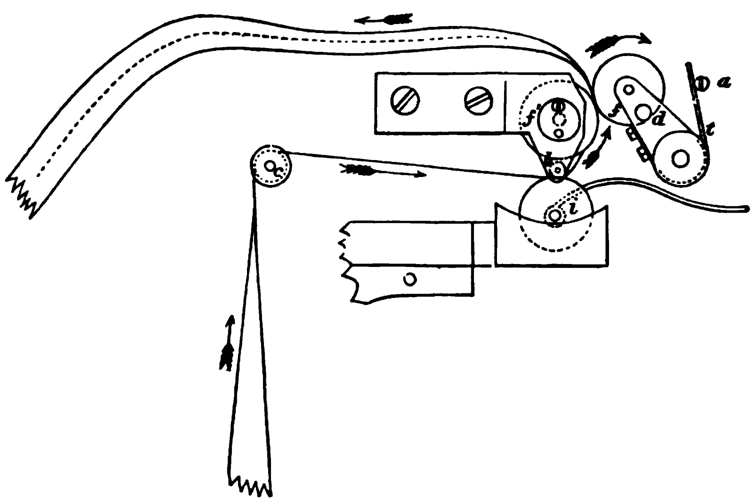
the clockwork. In the latest instruments received, the paper wheel, for the purpose of easier protection, moves in a horizontal plane on a vertical axis, and is enclosed in a drawer under the board of the instrument. Paper reels are issued which contain about 400 feet of paper tape ⅝″ broad. The paper coloured slightly green is best for the eyes.

Putting on a new reel of paper.—Take out the wooden block on which the paper has been coiled; remove one of the cheeks of the paper wheel; and place the reel of paper on the axis of the paper wheel against the remaining cheek, in such a manner that the clockwork pulls on the paper in the direction of a tangent to the reel. Then replace the other cheek, and fasten it by its screw. The space between the two cheeks should be somewhat wider than the width of the tape, in order not to cause much friction against the edges of the paper when unrolling. It very often happens that the different layers of the paper disc stick together, and that consequently a larger force is required to unroll the paper with the standard speed, than can be expected from the clockwork. In such a case unroll the disc of paper by hand, and roll it up again.

The paper guides and friction rollers.—Figure 14 gives a view of this arrangement when the paper wheel moves in a horizontal plane, enclosed in the drawer of the instrument board. Suppose the disc has been properly placed on its wheel in the drawer; then the free end of the tape is led *over* the guide *c*, and *under* the steel roller *b*, *between* the two friction rollers *f′* and *f*. The roller *f′* is driven by the clockwork, while the roller *f* is not in connection with the clockwork, but is pressed against *f′* by the spring *t*. Hence when *f′* is driven by the clockwork in the direction of the arrow, *f* is driven by friction in the opposite direction, and therefore the

paper between the two rollers is drawn out in the direction of the arrow. The roller *f* can be lifted by the handle *d*; it will be convenient to do so when introducing the paper between the two rollers. *a* is a pin against which the spring *t* rests. When the clockwork starts, and the paper is drawn out it passes tightly *under* the steel roller *b*, and consequently the inking-wheel *i*, if

Fig. 14.



pressed against the paper at this point, can produce an accurate mark.

The paper guide *c* must have its adjustable washers so arranged that the tape is directed to the middle of the friction rollers, or better, that the mark is made in the middle of the paper. Further the two washers of the guide *c* should be always placed so far distant from each other that the paper employed, which frequently varies in width, can roll out quite freely without rubbing with its edges against the washers. In the course of time it may happen that the spring *t* loses its force, and consequently *f* is not pressed sufficiently against *f′*, causing irregula-

rities in the running out of the tape. By unscrewing the pin *a*, and straightening the spring *t* somewhat, its force may be restored. Two springs (*t*), one pressing on each end of the roller *f*, are more trustworthy, but they should press equally strongly. The axles of *c*, *b*, *f'*, and *f* should move quite freely, and an occasional oiling of their bearings is advisable.

Fig. 15.

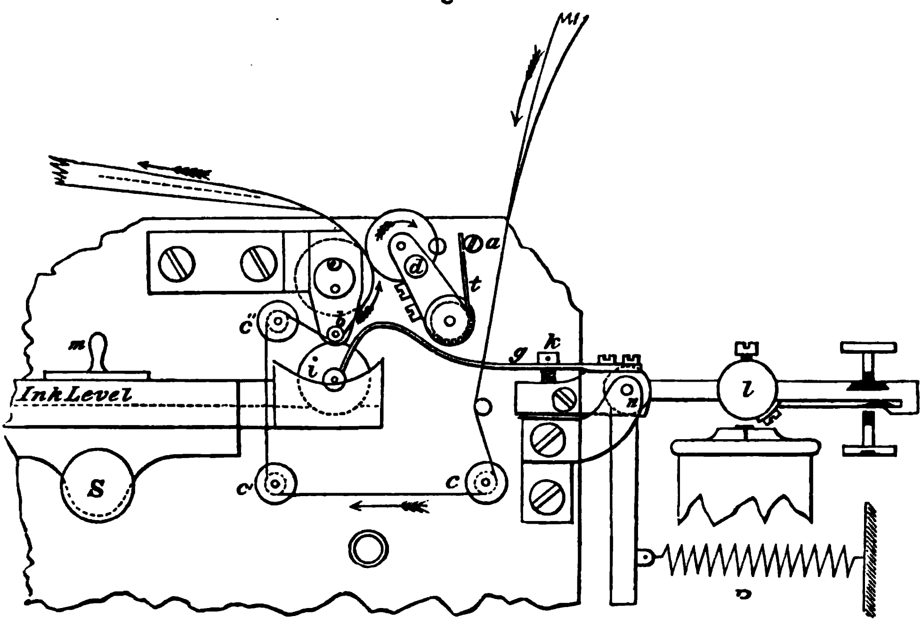


Figure 15 gives the same arrangement when the paper-wheel moves in a vertical plane.

In this case the paper has to pass round the three guides *c*, *c'* and *c''*. Further explanation is not required.

Ink-holder and Inking-wheel.—Fig. 15 gives the view of these arrangements. When the armature *l* is attracted, the inking-wheel *i* must press against the paper at *b*. The force with which this pressure is made can be regulated by the screw *k*. The more the screw *k*

is screwed in, the less becomes the pressure for a given adjustment of the instrument, because the printing arm *g*, fixed rigidly to the lever of the armature, acts like a spring. The lever itself and the printing arm *g* turn round a common axle *n*. The printing wheel *i* is fixed rigidly by friction to a small axle which has two bearings essentially different from each other. Namely, outside the instrument the axle of the printing wheel turns in an eye of the printing arm *g*, while inside the clockwork the axle of the printing wheel is in connection, by means of a short spindle carrying a cog wheel in gear with the clockwork. Hence the printing wheel, when the clockwork starts, is kept constantly rotating, without its free movement in a vertical plane (up and down stroke of the printing arm) being interfered with in the slightest degree. The bearings of the printing wheel are apt to become clogged with ink, preventing the free rotation of the wheel. In this case apply a few drops of olive oil, which mixes freely with the ink and clears the bearings. As the printing wheel is merely fixed by friction to its axle, it may become loose in time, which will show itself by the wheel producing only dots. In such a case fix the wheel by turning it round its axle as if it were a screw. In the same manner the wheel is to be fixed on its axle after having been pulled off for the purpose of cleaning. The vessel containing the ink can be taken off by unscrewing *S*. This need only be done when cleaning the ink-holder but *not* when putting in fresh ink.

The ink should not stand higher in the vessel than to produce a rim of ink on the wheel of about 1 to 2^{mm} (when turning round and marking) broad. If the wheel is allowed to dip deeper into the ink, the marks on the paper are apt to become blotted, besides the ink clogging the bearings of the wheel. The cover *m* should only

be taken off when putting in fresh ink. Caution should be used in filling the holder with ink that none is splashed on to the holder or framework of the clockwork, as otherwise the ink is sure to find its way into the clockwork, spoiling the instrument by clogging the bearings and wheels.

Printing Ink.—The ink is generally supplied in small glass bottles. Always shake the bottle before pouring out the ink. Always keep the bottle corked. The ink being a fat ink cannot be thinned with water, which would entirely spoil it. If the ink should become too thick, some olive oil may be mixed with it. If the ink contains too much oil, it will show itself by each mark made on the paper becoming surrounded by an oily rim.

Rules for adjusting an Ink-writer.

Screw down the adjusting screw *k* in order to have ample play for the printing arm.

Adjust the electro-magnetic part of the ink-writer, *i.e.*, the play of the armature and the strength of the spring, *P*, &c., &c., which is done in exactly the same manner as laid down for sounders.

Arrange the paper tape according to instructions.

Press down the armature of the electro-magnet, either by hand or electrically, and carefully screw up the adjusting screw *k* until the printing wheel almost touches the paper at *b*, but not quite.

Start the clockwork, and observe whether the paper is drawn out regularly, and at a speed of about six feet per minute.

Shake the bottle containing the printing ink, and pour out ink very carefully and slowly into the ink-holder, while the clockwork is started and the armature pressed down. Observe the ink-wheel, and stop pouring in ink as soon as a rim of ink is formed on the ink-wheel of about 1 to 2^{mm} in width. Do not splash any ink on

the instrument, and keep the cover *m* on the ink-holder.

Start the clockwork, press down the armature, and adjust *k* until a clear line is marked on the paper. Let the armature go, and no line should be marked on the paper. Now give the finest adjustment to *k*, by working the instrument electrically, until the signals are produced quite clearly.

See whether the signals are made in the middle of the tape; and if not, adjust the paper guides accordingly.

Do not allow the clockwork to run down fully.

Do not waste paper tape by letting the clockwork run when no message is received, or only an inland message, which has not to be recorded on tape.

Do not allow any slack of paper tape, but keep it winding up on its wheel.

When once the sounder part of the ink-writer has been properly adjusted, it is *not* required to touch it again, with the exception, perhaps, of the spring *P*. If the play of the armature is altered, it is clear that the printing-wheel must come out of adjustment also.

Note.—It not unfrequently happens that ink-writers are employed which either do not function properly as such, or not at all. *This is not allowed.* Whenever there is an ink-writer employed it must be in perfect working order, although the signallers may not read the messages from the tape.

The paper tape is issued in boxes lined with tin and soldered up. These boxes should be opened out one by one as required, and the tape in stock should be kept in a dry place.

XXIV. *Galvanoscopes.*—These instruments are designed for the purpose of merely indicating the presence of electric currents without affording the means of

measuring them. Galvanoscopes may be used in all "null methods" for the comparison of conductive and inductive resistances and of electromotive forces, and then these instruments must be constructed exceedingly sensitive; or they may be used in direct connection with the electric telegraph for the purpose of reading signals. Here we have only to do with the latter application. Any magnetic needle swinging freely either in a horizontal or in a vertical plane, surrounded closely by a coil of insulated copper wire, represents an ordinary galvanoscope. Thus we have vertical and horizontal galvanoscopes. The latter are preferable in all cases where sensitiveness is requisite. The common needle instrument is a vertical galvanoscope. Many forms of galvanoscope have been tried in India, but none has been found to answer so well as the *small Line Galvanoscope* which was introduced by Sir W. O'Shaughnessy. It is exceedingly simple in construction, sufficiently sensitive, and cheap.

Line Galvanoscope.—It consists of a small wooden frame, filled with insulated copper wire, each end of which is connected to a terminal with hand screws. The coil can be short-circuited by a plug being inserted between the two terminals. The magnetic needle is 17 mm. long, 4·7 mm. broad, and weighs about 0·435 gramme. It is made of Wolfram steel and swings on a steel pivot riveted to a small brass plate, which latter is simply pushed into the middle of the coil. The needle swinging so closely over a metal plate is somewhat damped. An index made of paper is gummed on to the middle of the needle at right angles to its axis. The play of the index can be altered and limited by two copper stops, between which it moves. Two small bar magnets are used for directing the needle. The resistance of the coil varies between 50 and 250 ohms. If the line galvanoscope is in

order and properly adjusted, the needle gives readable signals with *one Milli-Oersted.*

An office which for traffic reasons has to read *calling signals* from a distant station by means of the *line galvanoscope* (inserted between the two ends of a line which passes through the office), is said to be *in* G *on that line.*

When connecting up a *line galvanoscope* the following should be remembered :—

The plane of the convolutions of the coils should be invariably parallel with the magnetic meridian. For this purpose place the needle with its index on the pivot in the coil, and turn the coil round until the needle, under the sole influence of the earth's magnetism, is parallel with the convolutions, which is indicated by the axis of the index being at right angles to the plane of the convolutions. In this position the coil is to be screwed on to the instrument table. Now place the two small bar magnets parallel with the convolutions at the bottom of the coil on the side of the index, and with their opposite poles facing each other in such a manner that the force exerted by the two bar magnets on the needle is of the same sign as the force exerted on the needle by the earth's magnetism.

The sensitiveness of the galvanoscope is simply adjusted either by altering the distance between the poles of the two bar magnets, or by shifting the copper stops; and the play of the index can be easily varied by altering the distance between the two copper stops. The paper index should be equally heavy on both sides of the needle, should have a clean cut rim on each side, and is best when paraffined. Further the needle should swing horizontally, and therefore if one pole should be found apparently or actually too light, some wax may be employed to make the two ends of the needle equally heavy.

Even without any directive magnets, the needle, after each deflection, should always return again to its original position of rest. The pivots are apt to rust easily, and should be cleaned from time to time with chalk and chamois leather.

For cleaning the centre of the small cup by which the needle rests on the pivot, a pointed match is best. To know whether the needle is in order, place it on its pivot before attaching the index, and turn the brass plate round the pivot as axis, when the needle, under the sole influence of the earth's magnetism, should invariably point in the same direction, *i.e.*, should not move with the brass plate. A needle if properly magnetised should carry on one pole its own weight in soft iron.

Low resistance galvanoscope.—If it is required to have many offices on the same line in *G*, then the total resistance introduced into the circuit must become considerable, and therefore may interfere with perfect communication, especially during low insulation of the lines. This influence showed itself always very clearly in case of the Calcutta-Rangoon line (1100 miles in length), which, being still a single wire, has to pass through no less than 10 intermediate offices connected up in *G*. These offices, although of themselves having scarcely any traffic, must nevertheless be kept in circuit for departmental and political reasons. The evil, however, became still more prominent when it was decided to work this line on the duplex system instead of doubling the wire. Then it became absolutely necessary to use, in the *G* stations, a galvanoscope of very low resistance, but still sufficiently sensitive to give readable signals through a considerable external resistance. The *low resistance galvanoscope* fulfils these requirements. It has a resistance of about 10 ohms only, and works well with 0·5 Milli-Oersted. As the currents employed for duplex work-

ing are more than 12 times this strength, the instrument will always function with safety.

Description.—The coil is very carefully wound with wire, surrounding the needle as closely as practicable. The magnet needle is very short and swings in an agate cup on a steel pivot, perfectly polished and shaped, quite close over a small brass plate, to which the pivot is riveted. This plate is fixed to the frame of the coil by two screws. Normal to the axis of the needle is attached a very light ivory index which, especially at its rims, is polished and rubbed over with black lead. This prevents the pointer from sticking to the limiting stops. The coil with its needle and index is hermetically enclosed in a small brass cylinder covered by a thick glass top. This cover is fixed by an india rubber ring which acts as a spring. To take the cover off, *turn it to the left* and *pull*. To put the cover on, *turn it to the right* and *press*. The limiting stops can be adjusted from outside without taking the cover off. The directing magnet is only slightly magnetised (almost soft iron), and has the form of a circular horse-shoe. This magnet slides outside the cover in a groove, and is kept in any position by a spring pressing against the magnet. As the middle line of the directing magnet is placed somewhat higher than the plane in which the needle swings, the magnet has a tendency to lift the needle, by which the friction between pivot and agate is reduced to a minimum.

Putting up the instrument.—Here the rules given for the line galvanoscope should be strictly adhered to, *i.e.*, parallelism of the plane of the convolutions of the coil with the magnetic meridian; placing the circular directive magnet in such a manner that its force on the needle is of the same sign as that of the earth's magnetism. It should never be attempted to remove the needle from its pivot without taking the plate out of the coil by

removing the two screws. The pivot is so fine that it is easily broken.

Battery Test Galvanoscope.—This instrument consists of a single magnet needle of large size, resting by an agate cup on a finely polished steel pivot, and swinging horizontally and quite closely over a brass or copper plate which acts as a damper. The needle is surrounded as closely as practicable by a few convolutions of thick insulated copper wire offering no perceptible resistance as compared with the internal resistance of a *single* Minotto cell. The plate over which the needle swings is marked on both sides of the zero point.

If a single cell is inserted between the two terminals without any additional external resistance in circuit, and the needle is deflected *beyond* the mark, then the cell in question offers less resistance than a fixed standard, in our case less than 30 *ohms.*

If a battery consisting of any number of cells is inserted between the two terminals, and the deflection is up to the mark, then the average resistance of a single cell of that battery can also not be more than the maximum allowed, 30 ohms.* The needle should make 18 oscilla-

* The current c produced by one cell of internal resistance r, and E. M. F. e through the convolutions of the galvanoscope is expressed by

$$c = \frac{e}{r + g}$$

where g is the resistance of the galvanoscope.

Hence n such cells would give a current

$$C = \frac{n\,e}{n\,r + g}$$

But as $\frac{g}{r} = 0$ (even for the smallest r)

it follows that

$$c = C = \frac{e}{r} = \frac{n\,e}{n\,r} \text{ approximately.}$$

tions in 30 seconds, and 80 oscillations before coming to rest. The marks on the plate have been found by actual experiment with each galvanoscope—*i.e.*, a Minotto cell with an internal resistance of 30 ohms was joined up between the two terminals, and the deflection on both sides of the zero (with reversed currents) was observed and marked. The application of the instrument will therefore be clear. First test each cell separately, and join up for use only those cells which give a deflection equal to or greater than the marked deflection. A battery containing only such cells should then give also a deflection equal to or greater than the marked one. If, then, the deflection becomes smaller, a foreign resistance must have been introduced, which can be easily localised by section tests of the battery.

XXV. *Keys.*—An ordinary signalling key has always three terminals, viz., terminal 1 in connection with the front contact of the key, to which the copper pole of the line battery is attached; terminal 0 in connection with the body of the key to which the instrument-bar of the line commutator is connected; and terminal 2 in connection with the rest contact of the key to which the relay is connected.

Both front and rest contacts consist of platinum. The front contact, which acts as the anvil, is made stronger than the rest contact. The *play* of the key can be regulated by a screw which passes through the lever, and presses against the rest contact. The *play* should be made as small as possible in order to facilitate rapid signalling, and to decrease the noise. A good signaller invariably works with a key of small play. When the proper play has been adjusted, the screw is to be securely fixed by its jam-nut. The force with which the contact screw presses against the rest contact can be regulated

by a spiral spring. This spring should be adjusted tight enough to make the rest contact secure. As a connection between any two points by mere rolling contact * cannot be depended upon, the lever of the key is connected directly by a brass spiral with its bearings.

For many years only the *Siemens' key* has been used, excepting on school, railway, and testing instruments, where the *Douglas* pattern, being cheaper, is employed. It is not so good as the other, because the contacts cannot be cleaned easily, and are partly covered.

Any working contact of a telegraph instrument should be always placed easy for examination and cleaning.

Furious hammering with the key is strictly prohibited.

The keys used for duplex working are based on the principle of the discharging key described in Par. XIII., which was introduced in 1870.

Further, for testing purposes special keys are used.

Insulation:—Between the lever and the working contact with the lever at rest; between the lever and the rest contact with the lever depressed.

Conduction:—Between the lever and the rest contact with the lever at rest; between the lever and the working contact with the lever depressed.

The ordinary signalling keys are issued quite separately from the signalling instruments. The key is to be screwed on to the signalling table by two brass screws †

* This principle of constructing telegraph instruments should be always adhered to. For instance, the relay tongue should be connected with its bearings. Only care must be taken to do it in such a manner that the sensitiveness of the relay is not diminished.

† Iron screws are not to be used any more, because in this country they invariably rust in, and cannot be removed without breaking them. In fact the use of iron in any form should be restricted to those parts of the instruments only for which iron or steel is essential electrically. Mathematical instrument makers have acted on this principle long ago, and the manufacturers of telegraph instruments can do nothing better than to follow in the footsteps of this older branch of small mechanics.

on the right side of the instrument, and about 25 c.m. distant from the front edge of the table.

XXVI. *Commutators, Switches and Plugs, Line Commutators.* — They are used for convenient and speedy interchange between lines and instruments, and in addition for testing purposes. The smallest line commutator issued is for three lines. Offices where only *two* lines enter are to use the circular battery reverser on ebonite, which, in this case, fulfils the same purpose equally well and cheaper. The line commutator should be invariably connected up between the lightning discharger and instruments.

It may be put up either vertically or horizontally, but always in such a place that it can be conveniently got at and examined.

Fig. 16 gives the diagram of the connections in the case of a commutator for four lines.

The line-bars L cross the instrument-bars J at right angles, and are insulated from each other by ebonite. Each line-bar can be connected with each instrument-bar by a screw. This screw drops through the instrument-bar, and then screws into the line-bar underneath. Hence, in order to make the contact safe, the screw must be invariably screwed down fully, *i.e*, so that its head presses against the instrument-bar. The usual plugs are not used in this case, because their contact cannot be considered safe enough. T and T_1 are the two testing bars; T is in every respect similar to a line-bar, only it must not be connected to a line. In the holes h and t fit the usual stoppers, which are only used for testing purposes. Each line-bar L is connected through the line plate of the lightning discharger with a line. Each

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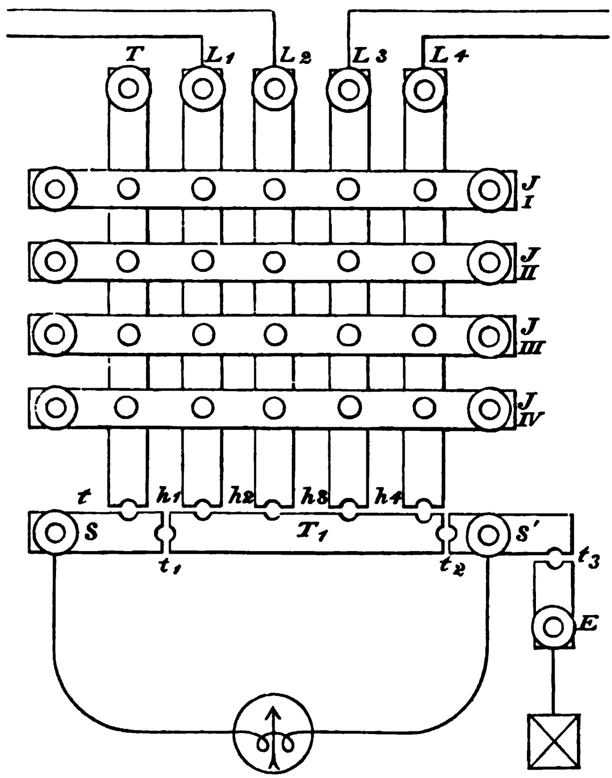
Gun-metal, from a mechanical point of view, will invariably act equally well as iron or steel, and the metal electrum, well hammered, gives very constant springs of any strength and shape.

instrument-bar is connected with the lever of a key. In order to be able to branch off the leading wires to the keys on both sides of the commutator, which is required for the sake of convenience and symmetry, each instrument-bar is provided at each end with a connection screw. To the screws *S S'* are connected the two terminals of the *tangent galvanometer*, while to the screw *E*

Fig. 16.



the *instrument earth* is to be connected. Although the different modes of connecting up a commutator can be easily understood from the diagram, for clearness sake a few examples may be given :—

Working the lines in S and T. In this case no stopper is to be left in the holes h and t, and each line-bar is to be connected with one instrument-bar by *one* screw only. Suppose, for instance, that line L_1 works instrument J_1, line L_2 instrument J_{11}, &c., then the screws must be put in the holes 1 I, 2 II, 3 III, and 4 IV.

Working the lines in G and D, and the connections being made not at the commutator but at the "*S T D*" switch, the same connections as for S and T working are applicable. But if G and D working of any two lines is to be done *directly* at the commutator, then the following are the connections:

G working at commutator through Tangent Galvanometer. Say, for instance, lines L_1 and L_2 are to be worked in G. Leave in the screw in 1 I, but remove the screw from 2 II, and place it in T I. Further, disconnect the instrument wire at J_1, or, which is more convenient, remove the plug out of the "*S T D*" switch of the instrument J_1. Put in plugs t, t_2, and h_2.

D working at commutator. Say, for instance, the lines L_1 and L_2 are to be worked in this manner. Remove the screw from 2 II and put it in 2 I; and take out the plug at the "*S T D*" switch of J_1.

Measuring the received current. Say from the line L_1.

Remove the screw from 1 I, and put in the plugs h_1, t_1 and t_2.

Measuring the sent current or the received current through the relay. Say, for instance, the current which is sent into or received from the line L_1 is to be measured. Remove the screw from 1 I, place it in T I, plug up t t_2 and h_1, and press down the key belonging to instrument J_1, when measuring the sent current, or leaving the key at rest when measuring the received current.

The commutator being placed in a box with a glass

cover, the latter should be always closed and locked, and the telegraph master on duty should keep the key; no change is to be made by anybody but the telegraph master on duty. The leading wires to the commutator must consist of insulated core. The holes in the box are just large enough to allow thick Hooper's core to pass through. In case of thinner core being used, this should be made tight in the holes, in order to close them entirely. Any spare holes in the commutator-box should be invariably closed up with the wooden stoppers issued for this purpose. Be very careful that the instrument-bars at the points where the screws *s* bite are perfectly metallic. The plugs and screws must fit perfectly.

It is advisable to mark the line-bars and instrument-bars by numbers, best by those which the lines bear in traffic.

Testing the Commutator.—Connect all the line-bars with the test-bar T_1, all the instrument-bars with the test-bar T, put in the stoppers t_1 and t_2, all other stoppers must be out, and remove all the screws. Then the insulation between these two systems of bars should be larger than 1 *megohm* even during the monsoon. Further, the resistance between any one of the line-bars or testing-bar T, and any one of the instrument-bars J when the corresponding screw connects both should be *zero.* The same must be the case between the testing-bar T_1 and any one of the line-bars, including the test-bar T, when the corresponding plugs are put in.

Switches.—The one commonly used is the $S\ T\ D$ switch, which serves for connecting up a station in S, T, or D by simply changing a plug. The pattern now issued has been devised with a view of facilitating its being cleaned, and in addition to admit of the common standard plug being used.

Another $S\,T\,D\,P$ switch, a drawing of which will be

found further on has been introduced for use in *parallel working*. The use of this switch will be readily understood by reference to the diagram and accompanying explanation. The plugs should fit firmly, and when no plug is in, the several terminals of any switch should be perfectly insulated from each other.

Plugs.—During the last few years the same new and improved pattern* of plugs has been issued, no matter for what purpose they may be used. This is absolutely required in order to be interchangeable. The brass or gun metal cones of these plugs become easily oxidised, especially when used near ebonite. Thus they are to be cleaned, from time to time, with chamois leather and chalk. When inserting a plug *press* and *turn it to the right*. When taking it out *pull* and *turn it to the left*.

XXVII. *Alarum. Trembling Bell.*—This is of very simple and inexpensive construction. It is mostly used in connection with the *Calling-in-Arrangement* and *Parallel Relay Working* to be described further on.

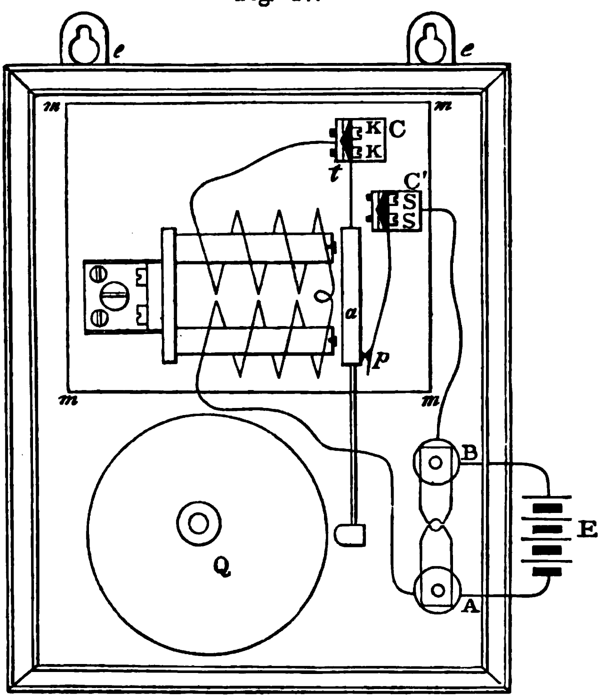
Fig. 17. gives the diagram of the alarum.

The coil of the electro-magnet has a resistance of about 30 ohms, and is to be worked by an E. M. F. = 4 (four local Minottos). The armature *a*, ending in the hammer, is fixed by a spring *t* and two adjustable screws *k* to the brass stand *C*, with which the one end of the coil is in permanent contact. The other end of the coil is in permanent connection with the terminal *A*, which contains a binding screw to which the one pole of the battery *E* is attached. The other pole of the battery *E* is to be connected either directly or indirectly with the terminal

* The old pattern plugs, where the metal part was simply screwed into the ebonite, and fixed by an ivory pin, were apt to break easily; because a stopper is liable to become rigidly fixed in its hole by oxidation, and when trying to take it out the pin broke frequently. This has been avoided by making the metal part, which fixes into the ebonite, square.

B which is in permanent contact with the brass stand *C'*. To *C'* is connected, by two adjustable screws *S*, a spring which is platinum tipped and presses against the platinum tipped point of the armature, so that at *p* a perfect contact is formed. The two springs must be adjusted in such a manner that they both tend to keep the contact *p* closed. In other words if either spring be withdrawn the other spring should follow a perceptible

Fig. 17.



distance. The terminals *A* and *B* can be short-circuited by a plug. The armature *a* is prevented from touching the iron cores by the usual brass rivets fixed in the centres of the cores. The distance between electro-magnet and armature can be roughly altered by the screws *K*, and finely by the screws *S*.

The bell Q is fixed to a metal rod by a screw with a jam-nut. The hole by which the bell fits on to the rod, is bored somewhat eccentric, so that by turning the bell round, the distance between the hammer and the edge of the bell can be varied. The whole arrangement is screwed on to a hard wooden board, which can be hung up by two brass eyes *e*. A small wooden box *m m* protects the electro-magnetic part of the alarum.

Hang up the alarum in a vertical position and always keep its cover on.

Action.—When no current passes, the circuit between A and B through the coil of the electro-magnet is metallically closed at the point p. But the moment a current passes, the armature a is attracted, consequently the contact at p is opened, and the hammer strikes the bell. Immediately after striking, the armature returns, the contact p is closed again, and a fresh current starts through the coil, and in this manner the action repeats itself, producing the ringing of the bell so long as a current passes the contact p.

Adjustment.—Hang up the alarum, attach the battery, and put in the plug. Now get first the right distance between armature and electro-magnet. The best method of getting roughly a good distance is by making it first as large as the construction and the strength of the current allows it to be, and afterwards to reduce it to about half by adjusting the screws K. Then adjust the spring until the contact at p is just made again, take out the plug and the bell should ring. While ringing do not touch the screws K any more, but adjust the screws S until the ring of the bell is regular and loud. After this the finest adjustment is made by turning the bell round, until a ring is produced which is both regular and clear.

Resistance :—Of the coils between A and B, with short-circuiting stopper out, and contact closed at p.

Conduction:—Between A and B with short-circuiting stopper in.

Insulation:—Between A and B with the stopper out but contact at *p* broken; and between A and core of electro-magnet.

Range:—Twenty-five with 1 and 10 cells.

Single-stroke Bell. This bell was designed in 1878 to meet the requirements of the State Railways; and its construction represents the results of numerous and varied experiments.

Fig. 18.

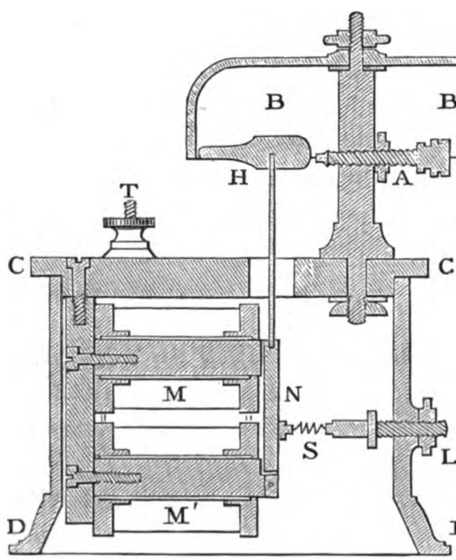


Fig. 18. gives a vertical section of the apparatus. *MM′* is a horse-shoe electro-magnet of the usual construction. *N* is the armature, and *S* the antagonistic spring, the tension on which can be adjusted by means of the screw *L*. The ends of the wire of the electro-magnet are attached to two terminal screws, only one of which, *T*, is seen in the section. *B B* is the bell,

which is struck from the inside by the hammer H, carried on a wire projecting from the end of the armature N, the play of which can be regulated by means of the screw A. The screw A and the bell B B are furnished with jamnuts; and the hole, through which the shank supporting the bell passes, is bored eccentrically, so that by turning the bell round, the striking of the hammer can be adjusted to produce a clear and distinct sound. D D is a cast-iron box; and C C is a wooden platform to which the whole of the apparatus, with the single exception of the screw L, are attached, Thus by unscrewing the screw L and pushing in the shank to which the antagonistic spring is connected, the whole of the apparatus may be lifted out of the box by means of the platform C C.

In order to increase the attractive force on the armature, by bringing one of its ends as near the core as possible, the principle of the *aimant boiteux* is adopted. The core of the lower electro-magnet M' projects; and in a cut made in its end, the armature N is pivoted on a brass axle.

Between the two terminals T T an "infinity" stopper is provided, by removing which the instrument can be thrown out of circuit. The following tests of this instrument are necessary:—

Resistance:—Of coils to be measured with infinity stopper in, corrected to 80° F., and marked on platform.

Insulation:—Between T and T with infinity stopper out; and between T T and hammer of bell.

Range:—Twenty-five with 2 and 20 cells.

XXVIII. *Lightning dischargers.** In India four dif-

* Lightning dischargers have been designed for the purpose of protecting objects from the influence of atmospheric electricity, which, especially in the form of "lightning," is known to have such power-

ferent kinds of lightning dischargers are in use, *viz*:— The *plate lightning discharger*; the *safety protector*; the *cable lightning discharger*; and the *spike dischargers* in connection with posts.

Plate lightning discharger. Close above, and parallel

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ful, and also very often destructive, effects. Benjamin Franklin, the great American physicist, must be considered the first who by rational experiments proved the identity between "lightning" and the "electric spark" of the physical laboratory. Although naturally many physicists before Franklin remarked the strong similarity between lightning and the common electric discharge, there appears to have been none who made actual experiments on the subject. Franklin proved the identity of the two phenomena by showing that *all* the effects which the electric discharge is able to produce can also be obtained with lightning. No sooner had the identity between lightning and the electric discharge been established, than Franklin, with his eminently practical mind, devised means by which lightning might be rendered harmless; and the first "lightning discharger" was erected according to Franklin's instructions in Philadelphia in 1752.

There cannot be any doubt concerning the useful action of well-constructed lightning dischargers in protecting houses, ships, &c., and the only question that remains to be solved is the best mode of construction for the least cost price. It appears that a satisfactory solution of this important question cannot be arrived at until our knowledge respecting atmospheric electricity is in a more advanced quantitative state. The chief point to be attended to is that any lightning conductor should offer no perceptible resistance from its highest point to the ground. Hence the lightning dischargers attached to buildings should be tested periodically just in the same manner as telegraph earths are tested, in order to see that the continuity from the summit to the earth keeps perfect, as otherwise the lightning discharger will do more harm than good.

A lightning discharger was first employed in a telegraph circuit by Steinheil in 1846. He used a plate discharger with a sheet of silk as the insulating medium. The principle of action involved in Steinheil's discharger is the same as in all other forms of lightning discharger that have since been suggested from time to time. Similar lightning dischargers are now employed on all the telegraph lines, but whether they act beneficially, and if so to what extent, appears to be by no means a fact established with certainty. In fine our imperfect knowledge of the phenomena opposes almost insuperable difficulties to our forming a correct opinion. Indian experience goes to prove that many instruments that are provided with lightning dischargers are annually damaged by lightning; and all that can be said of them at present is, that if they are kept clean they do no harm.

to, a strong metal plate, generally of cast brass, in connection with the earth, rest the *line plates*, of the same metal. Formerly, before 1868, plate dischargers

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The efficiency of differently constructed lightning dischargers may be tested as follows :—

Each telegraph lightning discharger of whatever construction consists essentially of two parts. Namely the plate or point connected with the line, and the plate or point connected with the earth. The first we will call the *line point* and the second the *earth point*. Line point and earth point are generally insulated from each other, either by air, or silk, &c.; in some cases rarified air (vacuum discharger), and in other cases a mixture of silica and carbon, forms the bad conductor between the two points. The latter is said to become conducting when a heavy discharge passes, while for the ordinary signalling currents the resistance offered is sufficiently high.

Connect the *line point* with an insulated channel containing slightly acidulated water, in which a metal electrode can be moved which is in direct contact with the earth and the *earth point*. Now charge the line point by a constant source of electricity of high potential (either by a uniformly working Ruhmkorff's coil or by an electric machine of which the charges are gauged by a measuring Leyden jar), and observe the sparks between *line point* and *earth point*. Now reduce the resistance of the water channel by moving the electrode until the sparks cease, then the resistance offered by the channel from the line point through the water to the electrode to earth is an inverse measure of the efficiency of the particular discharger. It is best to divide the channel into equal lengths and take the resistance offered by the channel of water to be proportional to the length. Say, for instance, that from the same source of electricity the spark in a discharger A ceases at length 20^{mm} while in another B the sparks cease at 10^{mm}. Then from the given source of electricity the discharger B has double the efficiency of that of A. Whether this ratio would also hold good when the force becomes much larger as is the case in practice, can, however, not be said with certainty. Our quantitative knowledge in this direction is too small.

Our Indian experience has given the following general results :—

Each year a large number of relays and also of sounders are destroyed by lightning. In many of these cases the line point and earth point are melted together. But many instruments are damaged when the lightning discharger shows no trace of discharge.

The large resistance relays which are worked on the long lines are less destroyed by lightning than the small resistance relays, which is natural.

During the last five years during which Duplex Telegraphy has been introduced, no case has come to knowledge of a condenser being destroyed by lightning.

made of cast iron were used. These did not answer well in India, for the discharging surfaces soon become rusted, and the grooves blunted. The line plates are insulated from each other as well as from the bottom plate. Two cones facing each other represent the best form of discharging surfaces. Hence to approach this form in a manner easy of manufacture, the line plates as well as the bottom plate, on the sides facing each other, are finely grooved in parallel lines, the grooves in the line plates crossing those in the bottom plate at right angles. Each crossing, therefore, approximately represents two cones with their points facing each other. The line plates are insulated from the bottom plate by ebonite or ivory washers, and in order that the line plates may not come into contact with each other, they are fixed in their respective positions by insulated stops.

Plate dischargers are made for *one*, *two*, &c., up to *six* lines.

If a greater number of line plates is made, the discharger becomes unmanageable for manufacture and transport.

Each line plate has two screws. To one of these is connected the line wire entering the office, to the other, through the commutator, the lever of the signalling key. The bottom plate has two screws, to one of which is to be connected the lightning discharger earth, while the other may be conveniently used for taking the earth tests. These screws should bite properly, and the surface between screw and plate should be quite free from lacquer and metallically clean. Each plate discharger is covered by a box with a glass top. *Never leave this cover off.*

As the efficiency of a plate discharger, all other conditions being constant, must greatly increase with the closeness of approach between the line and bottom

plates, care has been taken of late to reduce this distance as far as construction with due regard to safety allows of. In the new pattern dischargers four ebonite plugs are fitted into the bottom plate. The plugs are filed down until the line plate which rests on them is found to be not more than 0·25 mm. distant on all sides from the bottom plate. A steel gauge is used for adjusting this distance. In the old pattern, where the line plates rest on ebonite washers, such a close adjustment was difficult, if not impossible. This close approach between the line and bottom plates also necessitates, of course, greater care in keeping the discharger clean. Some of the new pattern have been issued as a trial, and up to the present no complaints have been received. Although the line plates are brought so very close to the bottom plate, they appear not to come into contact, nor is the insulation lowered. The plate discharger is to be connected up invariably between the lines and the commutator. The plate discharger is to be placed on a table in the signalling room * in such a manner that it can be conveniently examined.

Testing the discharger. Insulation:—Connect *all* the line plates, and measure the resistance between them and the bottom plate. This resistance should be always higher than one megohm even during the monsoon.

While taking this test press each line plate, one by one, in the middle as hard as possible, and neither contact nor any lowering of the insulation should be observed. In offices at which only a tangent galvanometer is available, the following qualitative test may be made: Connect up all the cells in the office successively, when the battery thus formed should not give the

* In some offices the discharger has been placed in the veranda. This is *not* allowed. In other offices the discharger has been connected up between the commutator and instruments. This is *wrong*.

slightest deflection through the thin convolution of the tangent galvanometer and the plate discharger in circuit. In neither of the experiments should earth be in circuit.

The Safety Protector.—Each line entering an office is to be provided with a safety protector, which consists of two galvanised iron wires pointed and tinned, approaching each other as closely as practicable in the line of their axes. The one wire is connected by a soldered joint to the line, projecting from it about 5·7 cm. This wire is most conveniently made of No. 8 I. W. G. The other wire consists best of the largest gauge available, and is connected durably with earth. These two wires should approach each other with their pointed ends within 3 mm. The whole arrangement must be made in such a manner that the two points cannot come into contact with each other, either mechanically or by rain or moisture. For the latter reason it is best to shelter the safety protectors from rain or dew, by putting them either in the veranda or, if this is impracticable, under a specially constructed roof. In addition the wires should incline at an angle of 45°. In many cases it will be convenient to attach the pointed earth wires to the terminal post, forming a kind of fork, the special form of which will be given in each particular case. When designing such a particular fork, all that is necessary to remember is that it should be as rigid as possible, and consist of the thickest gauge. The stem of the fork is to be brought into perfect metallic contact with the terminal post by binding it in several places, and soldering the bindings. In order to facilitate the putting up of safety protectors, a metal ring which carries on one side an adjustable pointed screw has been designed. This protector is put over the iron hood of the insulator, and then the screw is adjusted

to have its point within a small distance of the iron post.

Cable discharger.—Those at present in use are Varley's *vacuum dischargers.* They consist of two brass cones approaching each other closely in an exhausted glass cylinder. One of the two cones is to be connected to earth (terminal E) and the other to cable and line (terminals l and l'). Those in use in this Department are constructed with two *line cones,* and can therefore be used for protecting two cables. If only one cable is to be protected, the two dischargers may with advantage be connected across, and be used simultaneously for protecting the *one* cable. Several of these dischargers have become fused by lightning, proving that they have acted, and probably protected the cable. They are then spoiled, and it is not easy to repair them. Others have lost their vacuum, which can be seen on the discharge between the two cones being white and disruptive instead of blue and continuous, when placed in circuit of the secondary helix of a strong induction coil. In such cases it has also been generally observed that the discharge takes place in any other point of the instrument in preference to the cylinder. It appears that the two cones inside the cylinder are further distant from each other than are the terminals at several points outside the cylinder. When the vacuum is lost this difference comes into play.

These dischargers are protected by a glass cover. It is advisable, for additional safety, to connect the cables with the line through the usual plate discharger. They appear to act equally well or equally badly, but they have the recommendation that if they become fused, they can be easily repaired on the spot. It appeared to me, some years ago, that for the protection against lightning of short river cables, which form the links

between long overland lines, the best method would be to place on each end of the cable a condenser of larger capacity than the absolute capacity of the cable to be protected, and allow the discharge to take place in the ordinary manner by any of the lightning dischargers in use. As the cable represents a capacity with conduction resistance, while an ordinary condenser has only capacity without any appreciable conduction resistance, the charging of the condenser through the line wire should be much quicker, and hence a discharge at the lightning discharger might be able to take place before the cable had had time to receive a quantity of electricity sufficiently large to raise the potential of the cable conductor to any injurious extent. Further, by inserting between cable and condenser on either side a resistance coil, we have it in our power to reduce the charge of the cable.

The Spike Dischargers.—Each telegraph post, whether of iron or wood, terminates at the top in an iron spike. If the post is of wood this spike is to be connected by a wire with earth. This earth wire is at the same time used for connecting all the brackets on the same post, in order to decrease the injurious influence of cross leakage from wire to wire. That metal spikes, when connected to earth, may protect a wooden post against damage from direct lightning discharges is obvious, but for an iron post, which protects itself, spikes appear unnecessary, because the other effect, attributed generally to these spikes, *i.e.*, that they are able to protect the telegraph line from direct discharges, must be considered illusory. For, if direct discharges take place, they come generally from such elevated clouds that the small elevation of the spike above the wire is quite inconsiderable, and as further the number of points the telegraph wire exposes to direct discharges is infinite, while the spikes

represent only a very limited number of points, it is obvious that the action of the spikes in this respect must be imperceptible. However, spikes on iron posts can do no harm, and as they act in addition as an inexpensive ornament to the post, and in the case of a Hamilton's standard as a convenient means of closing up the top of the post, it is right to retain them. The *half* as well as the *three-quarter* Hamilton standards should invariably be provided with an iron spike connected by a wire with the iron portion of the post.

Repairing parties should always examine these posts carefully to see whether this is the case.

It is obvious that a wooden top post, with an iron spike *not* connected perfectly with the earth, is about the worst possible construction that could exist.

Thin wires connected between Line-Plate and Line.—To connect a thin and short wire between each *line-plate* and its *line* has been generally considered as an additional safety measure against the damage of instruments by lightning. Reasoning as well as experience shows, however, that such a wire cannot add anything to the safety of instruments. For, although the thin wire may melt, and actually is melted often by a heavy discharge, the latter must have been partly or entirely completed before the melting of the wire could occur, and therefore the damage in the other parts of the circuit through which the discharge passed, must also have been done. An effect cannot exist before its cause, although they may exist very closely together. Experience has shown that whenever the thin wire has been melted, the instrument as well as the lightning discharger was damaged. Thus it appears that these wires are useless, and as on the other hand they may obviously introduce variable contacts it is best *not* to use them. Should any of the lightning dischargers, especially those

in cable houses, be still provided with *thin* wires, the latter are to be removed and thick copper wires introduced in their place.

Insulators act as dischargers of a line.—It is clear that at all those points of an insulated line which approach closest to conductors in connection with earth, discharges of lightning may easiest escape. For instance each point of the line at which it is supported by the insulator, represents such a point of easiest discharge, especially if the insulator is covered by an iron-hood and the post consists of iron. For the construction of iron-hood insulators it should not be forgotten, that the distance between the iron-hood of the insulator and the nearest earth should be invariably smaller, at least in *one* point, than the distance between the stalk through the porcelain to the iron hood. This principle of constructing iron hood insulators has been purposely fulfilled in the *Douglas* pattern insulator, where the stalk through the porcelain is $\frac{13}{16}''$ distant from the iron hood, while the latter approaches the bracket to within $\frac{9}{16}''$. That this pattern of insulator is far less cracked and broken by lightning than others is well known. Insulators without iron hoods are of course most liable to be broken or cracked by lightning. In fact being able to construct iron hood insulators with considerable safety against the damage by lightning is almost the only point which, it would appear, justifies the application of iron hoods.

XXIX. *Earth.**—In India where gas and water pipes

* The first experiments on record, where the earth in form of water was used to complete an electrical circuit, are dated as far back as 1746. At this time Winkler of Leipsic discharged Leyden jars by using the River Pleisse as a part of the *discharging rod.* Winkler found that under such circumstances the effects of the discharges were not perceptibly different from those observed with a *discharging rod* consisting of metal only.

Le Monier of Paris, at about the same time, made similar experi-

are not generally available, the question how to form a durable connection of low and constant electrical resistance with the ground becomes of great importance.

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ments. He discharged Leyden jars through the water of the large tank situated in the garden of the Tuileries.

Watson extended these experiments. He established clearly that the earth, either in the form of water or damp ground, could always be used as a part of the electric circuit. His experiments were very numerous, and executed on a large scale in the neighbourhood of London in 1747. Franklin as well as De Luc verified Watson's results.

These are the historical facts which are generally stated to form the basis on which the present application of the earth in a telegraph-circuit rests. It appears that Basse's experiments have been almost forgotten, although they touch much more nearly the present application of earth in telegraph-circuits. For Basse of Hameln in 1803 made a series of experiments by which he established that the earth, either in the form of water or damp ground, could be used as part of a *Volta-circuit.*

He was the first who established the fact by using a voltaic battery instead of a frictional apparatus. These experiments of Basse's are so much to the point, that they well deserve prominent place in the history of telegraph progress.

In the same year, somewhat later, Erman of Potsdam verified Basse's results.

Aldini, in 1803, made also similar experiments at Calais with the sea, at Paris with the Seine, and at Alford with the river Marne.

Soemmering and Schilling, eight years later (1811), instituted a series of experiments with a view to establish the feasibility of using the earth as part of any electric circuit.

Thus it may be said that as early as the beginning of this century, the physical fact that the earth, in form of water or damp ground, could be used as part of any telegraph circuit was well established. It appears therefore strange that Steinheil's suggestions to use the earth in place of the return wire came so very late as 1837. For the interval between 1809 and 1837 is the very period during which the foundation of the present electric telegraph was laid, and as these early telegraph systems depended on the erection of multiple wires insulated from each other, a system which would have even proved fatal to the introduction of telegraphy for economical reasons only, if not for technical ones, it is difficult to conceive why none of the early inventors made use of that well-established fact to use the earth as part of the circuit. It would have halved at once the number of wires required, and would have been of far greater economical advantage than even later in Steinheil's time, when already only two wires were required to carry on telegraphic communications between any two stations. This strange neglect of applying a well-established and most valuable fact

Prior to 1868, the telegraph earth in a station was generally formed by an iron wire rope in contact with water or damp ground, in some cases only single iron

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becomes still more inexplicable when it is considered that Schilling and Soemmering, the two earliest inventors of telegraph systems, were both instrumental in proving, by experiment, the very same fact, which they did not apply or suggest should be applied in their telegraph systems. They used two wires for each separate circuit. Further, studying Steinheil's invention from his original papers, it will be observed that his suggestion to use the earth as the return wire was by no means a *direct one*, as it would have been, I think, if he had acted on the experiments mentioned above.

Steinheil wished to use the rails as the telegraph circuits in order to dispense with the expensive erection of telegraph wires. He found that he could not sufficiently insulate these rails from each other, hence this first experiment proved a failure. He used then *one* rail, and *one* insulated wire, when the success was perfect, for not only did the rail act as an earth but also as a direct conductor. Only after this last experiment he substituted *earth-plates* at both ends.

Gauss and Weber used also a return wire in their first needle telegraph system. It can scarcely be supposed that these learned physicists were unacquainted with the earth experiments made at the end of the last, and at the beginning of this century, which, as is well known, created a sensation throughout Europe since their application to telegraphy was then foreshadowed.

I believe, therefore, that this strange neglect must have been due to an erroneous idea fixing itself from the beginning in the minds of inventors, that a common *return wire* or *earth* could not be used, because the signals would become confused by such an arrangement. This would of course be perfectly true in the case of any two telegraph systems working independently of each other, and supposing the common *return wire* or *earth* offered a sensible resistance as compared with the resistance of the working circuit.

There are still living some great physicists who might give evidence on this strange inconsistency in the early progress of telegraphy. No less than twenty-eight years of delay have to be explained, *i.e.*, from Soemmering's invention of the chemical telegraph in 1809 to Steinheil's suggestion and application of the earth in 1837.

Steinheil's eminently practical suggestion of using the earth as the return wire for any telegraph-circuit had two great immediate advantages: it halved the number of wires at once; and it doubled the strength of the signalling currents, since the earth has no perceptible resistance. Both advantages are therefore important from an economical and technical point of view. Since the above was written Sir Charles Wheatstone and Cooke have died. There is only one of the great pioneers left—Weber.

wires were used, and in others the connection with the ground was formed by the iron guards of cables (disused or working). These iron ropes or wires were made long enough to offer a considerable surface in connection with the ground, and they were laid down in such a manner that the whole of their surface was in connection with the ground or water, *i.e.*, the several coils did not touch each other metallically. However it was found that these arrangements, although cheap and convenient, were by no means efficient, because the resistance offered by them was often exceedingly high and always inconstant. Further, the signalling currents produced such high polarisation currents that in many cases the regular working of the lines became injuriously affected by them.

Experiments were therefore instituted with the view of finding a better substitute, and it was finally established that "earth-plates" made of copper sheeting $42'' + 32''$, and $\frac{1}{8}''$ thick, answered the purpose far better. At the end of 1870 all offices in India had been supplied with these plates. Up to the present they have been very durable. Further their resistance is low and constant, and their polarisation is also very much smaller than with the former iron ropes.

Copper was selected, not on account of its greater conductivity, which is immaterial in such a case, but because its surface keeps metallic much longer than that of the cheaper metal iron. The metallic surface of the plate is essential for a low and constant resistance. Besides iron in the shape of a plate, which appears to be the best form, would rust through in a very short time. Iron plates well tinned would of course answer equally well, but they would not be cheaper than copper plates of equal dimensions. To make the thickness of the plate less than $\frac{1}{8}''$ is not advisable.

Description of the Earth-Plate.—Dimensions: $42'' \times 32'' \times \frac{1}{8}''$. *Material:* Sheet copper. *Leading wires:* Two insulated leading wires consisting of Hooper's Indian Cable core, each three yards long. These wires are soldered to the plate in four points. The joints are covered with tar and pitch up to the India rubber covering of the wire.

Installation of the Earth-Plate.—First examine the condition of the soldered joints. They should be intact. If the insulating covering has fallen off in some places, apply a fresh one. Measure the resistance between the two leading wires, which should be *zero*. Each earth-plate should be put down in a vertical position. Select a good position for the earth-plate, and as near as possible to the office. If a tank is available, the earth-plate must be put down in it, even if a short telegraph line should be necessary to do so. Otherwise a well, which is not used for drinking, may be used. In many cases it will be necessary to dig a special well for the plate. Only when the station is situated at too great an altitude, will it become necessary to bury the earth-plate in a stratum above water level. Such a plate ought to be well watered from time to time, especially during the dry season. It is also advisable, under these circumstances, to surround the plate with powdered charcoal. The best season for putting up an earth-plate is just before the rains set in. The plate can then be most easily put down under the lowest water level of the place. The top rim (longest side of the plate) should be at least one foot under the lowest water level. This in India, except in the hill stations, it will be almost always possible to do.

Care is to be taken that no strain is exerted on the two insulated leading wires attached to the plate. The

plate should therefore be fixed firmly in its vertical position. When the plate is buried in damp ground it is fixed of itself. If the plate, however, is only immersed in water without actually sticking in the ground, then some simple means must be adopted to fix it. If, for instance, the plate is sunk in a well, it is best fixed by two pieces of wood holding the top rim of the plate in saw-cuts. These two pieces are wedged in tightly between the walls of the well. If the plate is immersed in a tank without being buried in the ground, the best method of fixing it is by jamming the plate in between cross stays. When fixing an earth-plate it must not be forgotten that as little as possible of its metallic surface should be covered up, and that metallic supports must not be employed. The two insulated leading wires should be carried above in such a manner that it is convenient to get at their ends. The method usually adopted is to erect a telegraph post near the earth-plate, but *without touching it metallically.* The two leading wires may then be fixed over an insulator, fastened to the post, at an appropriate height.

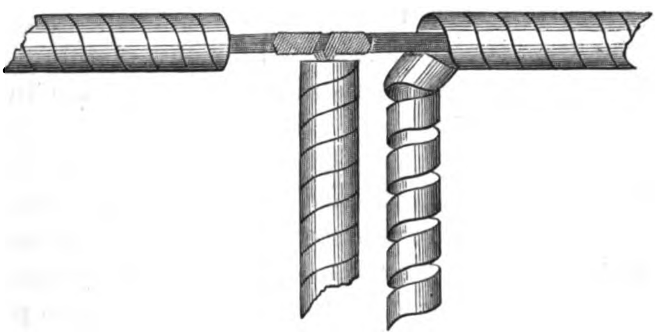
Close to the Office is to be erected another post, and between these two posts the leading wires are to be extended. If the distance between the two terminals becomes too large, a regular telegraph line is to be constructed, and two No. 50 I. W. G. iron wires, carried on the same insulator, are to be used for this purpose. The two wires attached to the plate are to be soldered on to these two line wires: one to each. At the Office terminal the two No. 50 wires are soldered together, and to this point two pieces of Hooper's core are soldered, long enough for one to reach the signal room, and the other the battery room.

Care is to be taken that all the points of the leading

*wires from the earth-plate to the office are perfectly insulated from the ground.**

The earth wire has to pass (supported on the usual wooden brackets) close to the different signalling tables in one *continuous length,* and best without any joint in the wire. At each signalling table, which contains generally two instruments, a piece of Hooper's core branches off. See Fig. 19.

Fig. 19.



The joints are to be made as follows:

Make a circular cut with a sharp penknife through the whole of the India rubber, and then with another cut follow for about two inches the visible spiral in which the India rubber is laid on, and unwind the spiral. Let

* This is necessary in order to secure the durability of the leading wire and to maintain the resistance of the earth constant. If, for instance, the leading wire was not insulated at all points before it reached the comparatively large surface of the earth plate, then the signalling currents would be able to escape to the ground at any of these points; and clearly at those points nearest to the battery and furthest from the "earth" the leakage would be greatest, supposing, of course, that the insulation of the leading wire was uniform throughout. Hence at all such points electrolytic action could occur, and the surface in connection with the ground being exceedingly small and the material limited, such an imperfectly insulated leading wire would run the risk of being corroded away, when ultimately the connection to earth would become imperfect.

this spiral hang down, and clean the copper wires. Remove the India rubber for about one inch from the end of the wire which is to be soldered on to the main wire. Open out its strands, and clean each wire singly. Twist three to the left side, and four to the right side from the middle of the exposed piece in the main wire. Solder the whole. Replace the India rubber covering, bind it, and coat the joint with Chatterton's compound.

The copper earth-plate is only to be used as *instrument earth* and *battery earth*, but *not* as *lightning-discharger earth.* For the *lightning-discharger earth* a separate earth is to be formed. In many of the offices the former iron ropes are still available and are to be used for this purpose.

Care must be taken that the *copper earth-plate* does not metallically touch the *lightning-discharger earth* at any point. How this can be ascertained by electrical test will be stated further on. As a rule the resistance offered by the leading wires from the office to the plate should not be more than one ohm. This is all that it is required to know, in order to be able to connect the office in any particular case by the proper line with the earth-plate. When an earth wire is attached to a connection screw it is *not* to be soldered. This has been often observed to be the case, but is obviously wrong, as otherwise the connection screw would not be required. This rule is equally applicable to the connection between any other wire and its connection screw. Contacts between wires and screws should be examined from time to time, and cleaned in order to have perfect metallic contact.

The electrical resistance of an earth. Suppose that two conducting bodies (electrodes) A and B are placed in contact with the earth at two different places, either by being buried in the ground, or immersed in water. Further, suppose that these two *electrodes* do not touch

each other metallically within the ground or within the water. Then it will be easily observed that such an arrangement offers a perceptible electrical resistance, *i.e.*, our planet when interposed by means of two electrodes within an electric circuit, offers a measurable resistance. Let this resistance be w'. It can be shown* that it is justifiable to put

$$w' = x + y$$

where x is the resistance which would exist between the electrode A and an indefinitely large electrode at a distance from it, indefinitcly great as compared with its dimensions, and where y has the same meaning with respect to the electrode B.

When we use, therefore, the term *resistance of an earth*, we simply mean the resistance which is offered by the planet between a given electrode of finite surface, and another imaginary electrode of infinite surface situated at an infinite distance.†

Hence by supposing a third electrode C in contact with the earth, but not touching metallically the other two electrodes A and B, we have obviously three independent equations

$$\begin{aligned} w' &= x + y \\ w'' &= x + z \\ w''' &= y + z \end{aligned}$$

where z is the resistance of the third earth (electrode C),

* See Appendix VI.

† This apparently round-about definition has been used for the purpose of doing away with the necessity of employing the term *resistance of transition* (*uebergangswiderstand*), to which we are unable to attach any definite physical conception. For the electrical resistance of a body can only be understood to mean the resistance offered by that body between two electrodes (of any shape or size soever) in perfect or imperfect contact with the body at different places; the electrical resistance of a body from one electrode only has no direct meaning.

and w', w'', and w''' are susceptible of direct measurement. Either of the three unknown resistances x, y, and z can therefore be calculated when w', w'', and w''' have been ascertained by measurement. This is the basis on which the measurement of the resistance of an earth rests, but before being able to determine the resistance of an earth we have to consider another phenomenon.

The potential of an earth, and the electromotive force between two earths. If we connect the two electrodes A and B by a suitable galvanoscope, a current will be observed almost invariably. Therefore the two electrodes must be of different potentials,* and the difference between these two potentials we call as usual the electromotive force between the two earths. Let this E. M. F. be denoted by e. Hence when measuring w, we have to act in accordance with the rules that have been laid down for the measurement of a *resistance* containing a *current.* Only if e remains constant, during two successive measurements, can w be accurately determined, when also e can be accurately expressed.

Measuring the resistance of an earth, and determining the E. M. F. between two earths. To ascertain the electric resistance of any one earth, two other earths,

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* The potential of a metal plate buried in the ground is determined by three separate causes. Firstly, the plate tends to assume the potential of the earth at the place where it is in contact with it (hence the *earth-currents,* observed between earth-plates); secondly, by the passage of signalling currents or the discharges of atmospheric electricity, the plate becomes polarised (hence the *polarisation currents* observed between earth-plates); and thirdly, two earth-plates, even of the same metal, when buried in the ground, act as a galvanic couple, giving rise to a current in any wire connecting them above ground.

Thus the resultant potential at any time of an earth plate will be the algebraical sum of the several potentials due to these three causes, each in themselves necessarily variable. Hence the potential of any earth-plate, as well as the E. M. F. between any pair of earth-plates (and therefore the *natural current* between them), must always be very variable quantities.

neither in metallic contact with each other, nor with the earth to be measured, are required.

According to orders there ought to be always two earths available at each telegraph office, *viz.*, the *instrument earth*, and the *lightning-discharger* earth. It is therefore only required to secure a third independent earth. This, in most offices, can be conveniently found by using the iron terminal post. Clean the part above its socket, and twist a thick bare copper wire tightly round the cleaned place. Attach a binding screw to the end of this wire to which to connect the testing instrument leading wire. Hooper's thick India-rubber core is best for the two testing wires, each just sufficiently long to reach from the testing instrument to any one of the three earths. We shall call x the resistance of the instrument earth. This value x includes the resistance of the earth leading wire, *i.e.*, from the points where the copper plate ought to act (in the battery room these points are clearly the zinc poles of the batteries; in the signalling room these points are clearly the terminals marked E of the instruments) through the insulated earth leading wire to the point where that wire is in contact with the copper plate. By y shall be designated the resistance of the lightning-discharger earth, consisting generally of an iron wire rope buried in the ground or immersed in the water. This resistance y counts from one of the two connection screws on the bottom plate of the lightning-discharger. While the resistance of the third earth (terminal post) we shall denote by z. The resistance z counts from the binding screw fixed to the wire which is twisted round the post.

Attaching now one of the testing wires to x (*i.e.*, to the earth terminal of one of the instruments, or to the zinc pole of a line battery), and the other testing wire to y (*i.e.*, to one of the connection screws on the lower plate

of the discharger, while the discharger earth is kept connected to the other screw), we can measure $x + y$; and similarly $x + z$, and $y + z$.

If the two testing wires offer a perceptible resistance, their joint resistance, which is known and constant, must be always subtracted from the measured value, when we get:

$$w' = x + y$$
$$w'' = x + z$$
$$w''' = y + z$$

$$\therefore \quad \left.\begin{aligned} x &= \frac{w' + w'' - w'''}{2} \\ y &= \frac{w' + w''' - w''}{2} \\ z &= \frac{w'' + w''' - w'}{2} \end{aligned}\right\} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (29)$$

and clearly by whatever special method the values of w may be obtained the above expressions for x, y, and z remain true.

The difficulty, however, is to get the right w in each particular case. For, as explained before, there is invariably an E. M. F. between any two earths which may be variable in itself, or become so by the action of the test current.

If such experiments, therefore, are not conducted carefully and intelligently, the results obtained may become quite erroneous, if not absurd. To give, however, detailed instructions we must discuss each available test method separately, and for clearness sake illustrate it by examples taken from practice.

The tangent galvanometer is used as the testing instrument.—1st case. Any two of the three *earths* when connected up in circuit with the tangent galvanometer,

produce sufficient current to give readable deflections through the thin and thick coils of the instrument.

This method is the most trustworthy one, supposing that the *reduction coefficient* of the tangent galvanometer is accurately known; for, in this case, no testing battery being required, the electrical condition of any two of these three "earths" has the greatest chance of keeping constant during the readings. First ascertain whether each two of the three "earths" give readable deflections through the thin coil and no external resistance in circuit. It is not advisable to trust readings much under 10°. Preliminary readings through the thick coil will not generally be required, since the resistance between any two earths will, as a rule, be comparatively low.

EXAMPLE.—Readings right and left:—

$$x + y \text{ in circuit give } \begin{cases} 9^\circ \text{ through thin coil.} \\ 15^\circ \quad \text{,,} \quad \text{thick ,,} \end{cases}$$

$$x + z \text{ in circuit give } \begin{cases} 12^\circ \text{ through thin coil.} \\ 20^\circ \quad \text{,,} \quad \text{thick ,,} \end{cases}$$

$$y + z \text{ in circuit give } \begin{cases} 8^\circ \text{ through thin coil.} \\ 10^\circ \quad \text{,,} \quad \text{thick ,,} \end{cases}$$

Further, the *standard cell*, through the thin coil, gives 70° before and after the above measurements. The internal resistance of the standard cell is known to be 20 ohms, while for the particular tangent galvanometer, with which the measurements have been taken, the following data are given:—

Reduction coefficient = 0·1
Resistance of thin coil = 100·2 ohms
,, thick ,, = 0·98 ,,

at the temperature at which the readings have been taken.

Then by Formula 7 we get

$$x + y = \frac{0{\cdot}1 \times 100{\cdot}2 - \dfrac{\tan 15^\circ}{\tan\ 9^\circ} \times 0{\cdot}98}{\dfrac{\tan 15^\circ}{\tan\ 9^\circ} - 0{\cdot}1} = 5{\cdot}25$$

$$x + z = \frac{0{\cdot}1 \times 100{\cdot}2 - \dfrac{\tan 20^\circ}{\tan 12^\circ} \times 0{\cdot}98}{\dfrac{\tan 20^\circ}{\tan 12^\circ} \times 0{\cdot}1} = 5{\cdot}17$$

$$y + z = \frac{0{\cdot}1 \times 100{\cdot}2 - \dfrac{\tan 10^\circ}{\tan\ 8^\circ} \times 0{\cdot}98}{\dfrac{\tan 10^\circ}{\tan\ 8^\circ} - 0{\cdot}1} = 7{\cdot}61$$

Further, the two testing wires used in each experiment have a resistance = 0·2 ohm, hence we have

$$w' = x + y = 5{\cdot}05$$
$$w'' = x + z = 4{\cdot}97$$
$$w''' = y + z = 7{\cdot}41$$
$$\left.\begin{aligned} x &= 1{\cdot}305 \\ y &= 3{\cdot}745 \\ z &= 3{\cdot}665 \end{aligned}\right\}\text{ohms.}$$

Now from Equation 6 we deduce

$$\frac{e'}{E} = \frac{\tan\ 9^\circ}{\tan 70^\circ} \times \frac{5{\cdot}25 + 100{\cdot}2}{120{\cdot}2} = 0{\cdot}0506$$

$$\frac{e''}{E} = \frac{\tan 12^\circ}{\tan 70^\circ} \times \frac{5{\cdot}17 + 100{\cdot}2}{120{\cdot}2} = 0{\cdot}0678$$

$$\frac{e'''}{E} = \frac{\tan\ 8^\circ}{\tan 70^\circ} \times \frac{7{\cdot}61 + 100{\cdot}2}{120{\cdot}2} = 0{\cdot}0459$$

where e' is the E. M. F. between x and y, e'' between x and z, and e''' between y and z, while E is the E. M. F. of the standard cell, which either may be taken as the unit,

or expressed in absolute measure, the volt. Suppose the standard cell is a Minotto (Daniell), then

$$E = 1{\cdot}079 \text{ volts.}$$

Hence

$$\left.\begin{aligned} e' &= 0{\cdot}0546 \\ e'' &= 0{\cdot}0732 \\ e''' &= 0{\cdot}0495 \end{aligned}\right\} \text{volt}$$

In this example the signs of the deflections have not been taken into account. It is clear, however, that if this be done, it can be ascertained which of the two *earths* in each experiment has a potential greater than the other. All of these three earths are therefore perfect.

2d case. Any two of the three *earths* do not give sufficient current when connected up in circuit with the tangent galvanometer to produce readable deflections. In this case it is therefore necessary to employ a testing battery. As the resistance to be measured, *i.e.*, w between any two of the three *earths*, is, as a rule, small (generally under 10 ohms), one Minotto as testing battery will in most cases suffice. The standard cell may be used for this purpose. Further, the readings must be taken through the thick coil without additional external resistance in circuit.

Example.—Insert the standard cell or any other element of known electrical condition in circuit, and take the following readings through the thick coil of the tangent galvanometer, all plugs in,

$$\left.\begin{aligned} w' \text{ gives} &\begin{cases} 25^\circ \text{ when } + \text{ pole to } x \\ 24^\circ \quad ,, \quad + \quad ,, \quad ,, \; y \end{cases} \\ w'' \text{ gives} &\begin{cases} 22^\circ \text{ when } + \text{ pole to } x \\ 21^\circ \quad ,, \quad + \quad ,, \quad ,, \; z \end{cases} \\ w''' \text{ gives} &\begin{cases} 20^\circ \text{ when } + \text{ pole to } y \\ 21^\circ \quad ,, \quad + \quad ,, \quad ,, \; z \end{cases} \end{aligned}\right\} \text{right and left readings.}$$

while the standard cell, which has an internal resistance of 16 ohms, gives 42° through the thick coil of the tangent galvanometer before and after the above measurements. The resistance of the thick coil of the tangent galvanometer, at the temperature of experiment, is exactly one ohm. The two readings in each case are required in order to eliminate the influence of any natural current which may exist between any two earths. This current, although weak (giving a deflection under 10° with the thick coil), may be, however, sufficiently strong to change the readings somewhat when taken with reversed testing current.* In the above example this has been actually the case. Taking, therefore, the means of the two tangents in each experiment we eliminate the influence of the E.M.F. which may exist between any two of the three earths under test. Thus we get

$$\tan 42^\circ = 0{\cdot}9 \propto \frac{e}{16+1}$$

$$\tan 24^\circ\ 30' = 0{\cdot}456 \propto \frac{e}{w'+17}$$

$$\tan 21^\circ\ 30' = 0{\cdot}394 \propto \frac{e}{w''+17}$$

$$\tan 20^\circ\ 30' = 0{\cdot}374 \propto \frac{e}{w'''+17}$$

* It should be always remembered that in order to eliminate the influence of the *natural current* two readings must be taken, *i.e.*, *one* when the test and natural currents are of the same direction through the coil of the tangent galvanometer, and the *other* when they are opposite. Hence the change must take place between the poles of the testing battery and the two "earths," and *not*, as it has been often done, by merely changing the poles of the testing battery with respect to the terminals of the tangent galvanometer. These latter readings must also be taken of course when necessary in order to eliminate the incorrectness of the galvanometer indications, making in all *four* readings to be taken in each such case.

Whence, by Formula 4,

$$\left.\begin{aligned} w' &= 16{\cdot}55 \\ w'' &= 21{\cdot}83 \\ w''' &= 23{\cdot}91 \end{aligned}\right\}\text{ohms.}$$

Subtracting 0·2 ohm, the resistance of the two testing wires, we get

$$\begin{aligned} x + y &= 16{\cdot}35 \\ x + z &= 21{\cdot}63 \\ y + z &= 23{\cdot}71 \end{aligned}$$

$$\therefore \qquad x = 7{\cdot}135\,;\ y = 9{\cdot}215\,;\ z = 14{\cdot}495.$$

The E. M. F. which exist between any two of the three *earths* can be calculated from each set of observations—

Thus $$\frac{e'}{E} = \frac{\tan 25^\circ - \tan 24^\circ}{\tan 25^\circ + \tan 24^\circ}$$

$\therefore$ $$= 0{\cdot}023$$

Similarly $$\frac{e''}{E} = 0{\cdot}025$$

and $$\frac{e'''}{E} = 0{\cdot}027$$

Or if we express E, the E. M. F. of the testing battery, in volts, which in this case is a single Minotto = 1·079 volts, we get

$$\left.\begin{aligned} e' &= 0{\cdot}0249 \\ e'' &= 0{\cdot}0274 \\ e''' &= 0{\cdot}0288 \end{aligned}\right\}\text{volt.}$$

Whether the values obtained for the resistance and E. M. F. are sufficiently correct, can be ascertained by observing the constancy of any one of the readings. If each deflection is independent of the time of closing the

testing battery, the results must be certainly correct within the limits of observation errors. The testing current being the stronger of the two, there will be a tendency to polarise the two "earths," hence the observations will be the more incorrect the stronger the test current used, and the longer it is allowed to act. Earth tests should therefore be made rapidly, and with an E. M. F. as small as practicable to get readable deflections (over 10°). As stated before one cell will generally suffice.

*The line testing arrangement is used for ascertaining the electrical condition of an earth.** The manner of testing in this case will suggest itself at once, *i.e.*, the resistance w between any two of the three earths is inserted in place of the *unknown resistance* of which the two ends are available, and balance is obtained with reversed testing currents. If the bridge is used, each w and e can be calculated by the general formulæ (2) and (3), vol. i. p. 16. If the differential galvanometer is used for testing, the corresponding formulæ are (2') and (3'), vol. i. p. 34.

In fact, all that has been said there for getting the accurate value of a resistance which contains in itself an E. M. F., is equally applicable here. It must not be forgotten, however, that, as in earth measurements the resistance to be measured is generally small, it will be necessary to use unequal branches in the bridge ($a > b$), and the shunt (p) in the differential galvanometer. That also here a testing battery of small E. M. F. should be used will be clear. Further, in some cases it will be noticed that balance with reverse currents, even when using unequal branches in the bridge, or a shunt with

* Either the Bridge or the Differential Galvanometer.

the differential galvanometer, cannot be obtained. This is due to the small resistance to be measured containing an E. M. F. which, although in itself perhaps quite small, is nevertheless large enough to make it impossible to reverse the direction of the current through the earth branch, by reversing the poles of the testing battery. In this case nothing else will succeed but lowering the resistance of the testing battery employed. For instance, say that with one single cell balance with reverse currents becomes impossible, then use a compound cell of two, three, &c., single elements until balance is obtainable. All this follows directly from the formulæ which express the electrical condition of any resistance containing a natural current.

Another case which deserves notice is when any two of the three earths produce sufficient current to make it unnecessary to apply a separate test current. In this case the resistance between any two earths may be found by considering it a battery, and using a differential galvanometer, the same experiments as given for this purpose in Par. X., vol. i. p. 39, are to be executed. If a bridge is used, the following procedure, not given in former instructions, may be followed:

The resistance which contains an E. M. F. is placed in the branch x of the bridge. The testing battery of the bridge is cut out, but the key is left in circuit, *i.e.*, when the key is pressed down the resistance in the testing battery branch of the bridge is zero ($f = 0$), and when the key is open $f = \infty$.

Now observe the deflection which the E. M. F. of the resistance to be measured produces in the galvanometer of the bridge (shunted, if necessary), and alter a, b, or w (the three variable branches of the bridge), either one, or both, or all three as the case may require, until, on depressing the key ($f = 0$), the deflection observed is the

same as when the key is open ($f = \infty$). In this case, as can be proved, we have *

$$x = \frac{bw}{a}$$

* If we use the same designations for the resistances of the six branches of the bridge as given in Fig. 1, vol. i. p. 2, the current G, which passes through the galvanometer of the bridge when an E. M. F. e acts in the x branch but none in the f branch, is expressed by

$$G = \frac{e}{N}$$

where

$$N = \frac{w\,(g+a) + a\,(g+x)}{w+x} + \left(x + \frac{w+x}{w+a} f\right) \cdot \left\{ \frac{w\,(a+b) + g\,(a+w)}{f\,(a+b) + b\,(a+w)} \right\}$$

Hence to keep G constant when f varies between 0 and ∞, we must keep N constant, *i.e.*, N must be independent of f. Whether such a condition between the other quantities a, b, w, x and g exists that f is eliminated from the expression of N, we find easiest by differentiating N with respect to f, and equating the result to zero.

Thus $\frac{d\,N}{d\,f} = 0$ must give the condition if such a condition exists.

Put

$$w\,(a + b) + g\,(a + w) = \alpha$$

$$b\,(a + w) = \beta$$

and

$$\frac{w\,(g + a) + a\,(g + x)}{w + x} = \rho$$

which three terms are independent of f.

Thus

$$N = \rho + \frac{\alpha}{f\,(a + b) + \beta} \left\{ x + \frac{w + x}{w + a} . f \right\}$$

and $\frac{d\,N}{d\,f}$ vanishes

when

$$\frac{w + x}{w + a} \beta - x\,(a + b) = 0$$

Substituting for β its value, and reducing we get at last

$$bw - ax = 0$$

which is the possible condition, and proves that the method of measuring x is correct. This method of measuring an electrical resistance which in itself contains an E. M. F. is due to Mr. Mance. See Phil. Mag. Vol. XLI., p. 315.

The same designation of the different resistance branches has been used here as in Fig. 1, vol. i. In case of measuring the resistance between any two of the three earths x stands for that resistance. In case of determining the resistance of a battery x stands for that resistance.

Examples are not required, since officers, who have a bridge or a differential galvanometer at their disposal, are already well acquainted with the details of such measurements.

Highest resistance allowed of an earth in India.—Any *earth* used either as instrument and battery earth in form of a copper plate, or as lightning-discharger earth in form of an iron rope, should not offer more than 10 *ohms resistance.* Experience has shown that this is not too low for any part of India. If the resistance is higher than 10 ohms it will always be due to circumstances which can be altered, and it is the duty of the officer in charge of an office to find out the cause of undue resistance, and to remedy the defect.

Records of earth tests. —These should be as complete as the battery tests. The *earths* in each office should be tested at least *once* a week, and the resistance should be calculated for each of the *three* earths used for testing.

Criterion whether two earths are in metallic contact.—It has been stated before that the three earths in an office must be independent of each other, *i.e.*, must not be in metallic contact anywhere. In other words the three earths must neither touch each other underground, nor under water; nor must the wires leading to them be in contact. Otherwise their separate resistances (x, y, and z) cannot be determined in the manner given. Hence it is of importance to know whether this condition is fulfilled.

Firstly.—See whether the two earths give any natural current. If no such current is observed, not even the smallest, then we conclude that either the two earths are in metallic contact somewhere external to the testing instrument, or if not, that the E. M. F. between the two earths is exceedingly small, and their joint resistance so large as to prevent a current being produced of sufficient strength to be observed with the given testing instrument.

Secondly.—Now measure this joint resistance. If this resistance is zero or at least not sensibly larger than the resistance of the leading wires which connect the two earths with the testing instrument (this resistance is always known, or if not, can be easily measured), then the two earths in question must be in metallic contact, either somewhere between the testing instrument and the ground, or under the ground itself.

Although the subject of earth has been treated very fully, it may be advisable to recapitulate clearly and concisely the general rules to be adhered to.

General Rules.—Every telegraph office in India is to have three independent earths; the copper plate, used as the earth for instruments and batteries; the lightning-discharger earth; and the testing earth.

Proper arrangements are to be made for testing the electrical condition of these three earths quickly and conveniently. Such tests should not require more than 10 minutes for their execution.

The leading wires from the office to the copper plate should be perfectly insulated at all points from the ground, and their resistance must not exceed *one ohm.*

The two testing wires should be as short as possible, and their resistance should be known.

All of the three earths should be below lowest water level of the place, if possible. This is particularly

required for the copper plate, and the lightning-discharger earth.

The best season for putting down new earths is, therefore, shortly before the rains set in.

At hill stations, and others where damp strata cannot be reached, or at least not during the dry season, watering is required. In such cases it is also good to surround the earth-plate with powdered charcoal for six inches thick on all sides.

The copper plate is to be put up vertically, and is to be fixed in such a manner that no strain is exerted on the leading wires.

The earths are to be tested at least once a week, and the results are to be recorded.

The methods of testing the earth without a testing battery give the most trustworthy results.

When testing the earths the office should neither receive nor send on any of the lines. Hence the best time for testing is on a Sunday between 8 and 16 hours.

XXX. *Specification.*—It is of the greatest importance when ordering telegraph stores, as, for instance, instruments, insulators, cables, copper wire, iron wire, telegraph posts, &c., &c., that a well considered specification should be carefully prepared and printed, copies of which should be forwarded to the manufacturers or suppliers of the required stores, and to those officers who are to receive or to use them. If this is done in a regular manner, a great deal of annoyance and confusion may be avoided. Moreover, a well considered and practical specification should necessarily contain all that the latest advances in telegraphy have shown to be within reach; and thus not only assist in getting the best, but also stimulate manufacturers and others by a healthy competition to exceed the terms of the specification.

Hence specifications will *indirectly* advance telegraphy. They will invariably have the desired tendency to raise judiciously the standards of efficiency.

The special manner in which a specification should be prepared, and all that it should contain, will, of course, depend on the kind of stores to be ordered, and therefore it is impossible to give a general example. All that can be done is to lay down the headings of the specification, with some remarks which may prove useful.

Purposes for which the stores are required.—It may at first sight appear that such a statement is entirely unnecessary, but considering that the supplier or manufacturer of stores, when acquainted with the special purposes for which they are required, may be in a position by practical knowledge of the subject to increase to his own credit the efficiency of stores, as it is reasonable to expect any honest business man would always endeavour to do, it will *at once* be evident how very useful to real advance such a detailed statement may become.

Detailed description of stores. — Kind, quality, dimensions, &c., should be stated, and if necessary accompanied by special drawings. Defects of former deliveries should be pointed out.

Tests required, mechanical and electrical.—The standard for measuring should be clearly stated, and if necessary the special methods should be given by which the tests are to be executed. The preparation of this part requires special technical knowledge, and must be done very carefully in order to insure an efficiency which can be expected, without preventing the manufacturer or supplier from fulfilling the terms of the specification.

A reasonable margin for manufacturing must, of course, always be given, since it is impossible to make identical things of whatever kind. The magnitude of the margin will necessarily depend, on the one hand, on the kind of

stores, and, on the other hand, on the state of the manufacture of the branch to which the stores belong.

Suggestions for packing.—As a rule manufacturers should know best how to pack up their own stores for a safe arrival. Experience, however, has shown that this has not always been the case. The climatic conditions of India are so very different from those of Europe, and the sea voyage is a long one, and through the hottest parts, that practical suggestions from persons acquainted with all this, and with the kind of stores, may sometimes prove of essential value to the manufacturer or supplier in Europe.

General Remarks.—Specifications should be drawn up with an endeavour to obtain the best stores, but not with the intention of raising unnecessary difficulties. A specification must therefore be drawn up by a man well acquainted with the subject, who personally knows the difficulties of manufacturing, and is free from red-tapeism.

APPENDIX I.

SHORT MATHEMATICAL THEORY OF THE TANGENT GALVANOMETER.

In 1820 Hans Christian Oersted of Copenhagen discovered the action of the electric current on the magnetic needle. He observed that whenever an electric current passed through a wire in the neighbourhood of a freely suspended magnet, the latter was deflected from its original position of rest, and returned to it so soon as the current ceased. He also noticed that the deflection caused by a current of given strength was greatest when the plane of the deflecting wire coincided with the plane of the magnetic meridian. Disregarding all the other important consequences of this remarkable discovery as foreign to the present investigation, it is only right to state here that it has formed the basis of all the methods subsequently used to indicate currents, and to measure their strength accurately. Shortly after Oersted's discovery, Professor Schweigger of Halle observed a very important fact, namely, that a current of given strength caused a greater deflection of the needle, when the wire conveying the current was turned into a number of convolutions, passing above and below the needle, insulated from one another and wound in the same direction. This led him to construct instruments called galvanoscopes or multipliers, by means of which very feeble currents could be easily detected. A few months later Professor Poggendorff re-discovered the multiplier. Though, of course, it was soon recognised that for any particular instrument the magnitude of the deflection of the needle was a certain function of the strength of the current passing through the coils, the determination of those laws which link current and deflection together was by no means so quickly arrived at. Many preliminary and accurate experiments had to be executed before such calculations could be attempted. Even now the problem of how any form of coil, through which a current passes, acts on a freely suspended magnetic system has not been solved in all its generality, on account of the general solution being highly intricate, and in many cases impossible in the present state of mathematical science. However, amongst all the possible curves into which a wire may be coiled, the circle presents the least difficulties to determining the required function; and the law that connects the deflection of the needle and the strength of the

current together, at least the approximate one, becomes very simple, *viz.*: when a current passing through a wire coiled into a perfect circle acts on a magnetic needle (of short length compared with the radius of the circle) suspended in the axis of the circle and free to turn in a horizontal plane, and the plane of the circle coincides with the plane of the magnetic meridian, the strength of the current is approximately proportional to the tangent of the angle to which the needle is deflected.

Based on this principle, Pouillet invented an instrument, which was consequently called the "tangent galvanometer," and which is the form that can be most easily applied for comparing the strength of currents, and especially for expressing them in absolute measure. Gaugain endeavoured to render the law of tangents still more approximately true, by placing the point of suspension of the needle in the axis of the circle at a distance equal to half the radius of the circle from its centre; and Helmholtz rendered the principle really practicable by placing a second similar coil at the same distance on the opposite side of the needle. Weber has quantitatively investigated the error introduced by using the approximate, but more simple, tangent law instead of the true expression.

Before entering on the solution of the problem for the tangent galvanometer, we must examine the action of an element of a conductor through which a current passes on a magnetic pole external to it, and not lying in the path of the current. For this purpose imagine a wire in space, through which a current passes, and forming any curve whatsoever. Let us take any point P in the curve, and ascertain its action on the pole m, which we will suppose is under no influence other than that of the current at the point P. Draw the tangent to the curve at the point P: this will be the direction of the current at the point P. Consider the plane which contains the tangent to the curve at the point P and the magnetic pole m. This plane is called the "plane of action," since the force exerted by the element ds of the conductor at P on the pole m is wholly transmitted in this plane and in none other. Under the action of the force exerted by the element ds, the pole m will move in a direction normal to the plane of action. Connect P and m by a straight line: let l be its length, and ϕ the angle it makes with the tangent at P. Then resolving the element ds along and at right angles to the line l, the latter component is alone effective—namely,

$$ds \sin \phi$$

The force under which the pole m moves out of the plane of action is then

$$df = \frac{m\,C}{l^2} \sin \phi \, ds \quad \ldots \quad \ldots \quad \ldots \quad \text{(I)}$$

the sign of which depends on the signs of C and m, where C represents the strength of the current at the point P, and m the strength of the magnetic pole.

This expression for the force exerted by the element of a current on a magnetic pole is partly the result of direct experiment, and partly due to theoretical considerations. It must, however, be accepted as the true expression for the force, since it leads to consequences the correctness of which can be tested by the most accurate quantitative measurements; and, so far as the accuracy of measurement allows, no error has hitherto been discovered in the principles laid down in formula (I).

To apply this expression to ascertain the force exerted by a current in any coil of wire on a magnetic pole, we have only to integrate the above function, which it may or may not be possible to do—presenting only mathematical difficulties, but none of a physical nature. Now suppose the curve formed by the wire through which the current C flows to be a circle, and the pole m to be situated in the axis of this circle, *i.e.*, in the line passing through the centre of the circle and normal to its plane. Then, clearly, the tangent at the point P is at right angles to the line l, or $\phi = 90°$; and equation (I) assumes the more simple form

$$df = \frac{m\,C}{l^2}\,d\,s \quad \ldots \quad \ldots \quad \ldots \quad \text{(II)}$$

Further, if we call α the angle which the direction of df makes with the axis of the circle; then the component $df \cos \alpha$ acts along the axis of the circle, and the component $df \sin \alpha$ acts at right angles to it. Now, it is clear that in a circle for each point P there will be another point P', diametrically opposite to it, exerting the same force df on the pole m, in a direction making an equal angle α with the axis of the circle; whence it follows that the two components of the force exerted by the current at the point P' are $df \cos \alpha$ along the axis, and $-\,df \sin \alpha$ at right angles to the axis. Thus, of the forces exerted by the current at the points P and P' on the pole m, the two components at right angles to the axis are equal in magnitude and opposite in direction, and consequently neutralise one another; but the two equal components along the axis act in the same direction and add their effects. Hence, calling $d\,F$ the resultant force (along the axis), we have

$$d\,F = 2\,df \cos \alpha = 2\,\frac{m}{l^2}\,C \cos \alpha\, ds$$

And, calling d the distance of the pole m from the centre of the circle, and r the radius of the circle, we have

$$l^2 = r^2 + d^2$$

and

$$\cos \alpha = \frac{r}{l} = \frac{r}{\sqrt{r^2 + d^2}}$$

$$d\,F = 2\,m\,C\,\frac{r}{(r^2 + d^2)^{\frac{3}{2}}}\,ds$$

$$\text{Whence} \qquad F = 2\, m\, C \frac{r}{(r^2 + d^2)^{\frac{3}{2}}} \int_0^{\pi r} ds$$

$$F = 2\, \pi\, m\, C \frac{r^2}{(r^2 + a^2)^{\frac{3}{2}}} \qquad \ldots \quad \text{(III)}$$

This expression, first given by Weber, is evidently absolutely correct when the following conditions are fulfilled:—

1. If the fundamental expression (I) is correct.
2. If the current is the same at all points of the circle.
3. If the curve formed by the wire is not only a true circle, but also a complete one, *i.e.*, the points of entry and exit of current are close together.

With respect to the first, it has already been stated that it can be taken as absolutely correct; the second is true in all practical applications; and the third is only a mechanical condition that can be more nearly fulfilled the better the workmanship is. Now suppose a straight, uniform, and indefinitely small magnetic needle suspended at the point m, and having two poles of the same strength m situated at equal distances from the centre of suspension of the needle, and that this needle is free to turn about its axis of suspension in a horizontal plane. Then, it is clear that the needle, when at rest, being parallel to the plane of the coil, a current C passing through the coil must exert on each of its poles a force F, in opposite directions, equal to that given in formula (III). We are, of course, unable to produce an indefinitely small magnetic needle, but we can make one the length λ of which may be neglected in comparison with the radius of the circle, and then the equal and opposite forces acting on the two poles of such a needle will constitute a couple S, tending to turn the needle about its axis of suspension, equal to

$$S = \lambda\, F = 2\, \lambda\, \pi\, m\, C \frac{r^2}{(r^2 + d^2)^{\frac{3}{2}}} \qquad \ldots \quad \text{(IV)}$$

When a current passes through the coil, each pole of the needle is acted upon by two forces, namely, by the horizontal component of the earth's magnetic force tending to keep the needle in the magnetic meridian, and by the force due to the current tending to deflect the needle from the magnetic meridian. Thus it follows that, under the combined influence of the two opposing couples, the needle will come to rest making some angle $a°$ with the magnetic meridian. Now, calling H the horizontal component of the earth's magnetism, the force it exerts on each pole of the needle may be resolved into two components—viz.:

$$m\, H \cos a° \text{ parallel to the needle}$$

which is neutralised by an equal force $m\, H \cos a°$ acting in the opposite direction on the other pole of the magnet; and

$$m\, H \sin a° \text{ at right angles to the needle}$$

which, with a similar force applied at the other pole of the magnet, forms a couple

$$\lambda \, m \, H \sin a^\circ$$

tending to turn the needle back into the magnetic meridian.

Similarly the force exerted by the current C on each pole of the needle may be resolved into two components, viz.—

$$F \sin a^\circ \text{ parallel to the needle.}$$

which is neutralised by an equal force $F \sin a^\circ$ acting in the opposite direction on the other pole of the magnet; and

$$F \cos a^\circ \text{ at right angles to the needle}$$

which, with a similar force applied at the other pole of the magnet, constitutes a couple

$$\lambda \, F \cos a^\circ$$

tending to turn the needle away from the magnetic meridian.

But, as the needle is at rest, the two turning couples must be equal.

$$\therefore \qquad \lambda \, F \cos a^\circ = \lambda \, m \, H \sin a^\circ$$

Whence

$$F = m \, H \tan a^\circ$$

and substituting its value for F from (III)

$$2 \pi \, m \, C \frac{r^2}{(r^2 + d^2)^{\frac{3}{2}}} = m \, H \tan a^\circ$$

or, putting

$$K = \frac{2 \pi \, r^2}{(r^2 + d^2)^{\frac{3}{2}}}$$

$$C = \frac{H}{K} \tan a^\circ$$

the expression given in the formula on p. 6, "Preliminary."

It is clear that the above formula must also hold good for $d = 0$, when the constant of the instrument K becomes simply $\frac{2\pi}{r}$, but in this case the needle must be still smaller relatively to any given r in order to fulfil the tangent law approximately.

Weber found that so long as the length of the needle does not exceed the fifth part of the diameter of the coil, the simple tangent law is sufficiently correct even for exact measurements, especially if the readings are never taken above 45°.

The investigation of the problem is less simple when the length of the needle is not assumed to be indefinitely small in comparison with the diameter of the coil of the galvanometer. The general expression

for the strength of the current then becomes (the needle being supposed to be suspended at the centre of the coil)

$$C = \tan a^\circ \frac{H r}{2 \pi} \left\{ 1 - \frac{3}{4} \frac{\lambda^2}{r^2} (1 - 5 \sin^2 a^\circ) \right\}$$

in which the second term within the large bracket is seen to be a correction on account of the length of the needle. It will be noticed that this correction vanishes when

$$5 \sin^2 a^\circ = 1$$

that is to say, when $a^\circ = 26^\circ\ 34'$. Some physicists, when making absolute measurements, have therefore so conducted their experiments as to obtain this deviation; but a better plan is to make the ratio $\frac{\lambda}{r}$ so small that the correction becomes insignificant. The correction has two unequal maxima: the lesser at $a^\circ = 0^\circ$, when it becomes $-\frac{3}{4}\frac{\lambda^2}{r^2}$; the greater at $a^\circ = 90^\circ$, when it becomes $+\ 3\frac{\lambda^2}{r^2}$.

At $a^\circ = 40^\circ$ about, the magnitude of the correction is the same as at $a^\circ = 0^\circ$.

In the case of any given instrument, the above expression may be written

$$C = \text{Const.} \tan a^\circ \left(1 + \frac{15}{4} \frac{\lambda^2}{r^2} (\sin^2 a^\circ)\right)$$

so long as the same needle is employed. If we compare two currents with this instrument, we have for the ratio of their intensities:—

$$\frac{C}{C'} = \frac{\tan a^\circ}{\tan a'^\circ} \left\{ 1 + \frac{15}{4} \frac{\lambda^2}{r^2} (\sin^2 a^\circ - \sin^2 a'^\circ) \right\}$$

Thus the error made by assuming the simple tangent law is represented by the fraction

$$\frac{15}{4} \frac{\lambda^2}{r^2} (\sin^2 a^\circ - \sin a'^\circ)$$

This error vanishes when $a' = a$; and the nearer a' is to a the smaller it will always be. It is greatest when one angle is 90° and the other 0°, when it becomes $+\ \frac{15}{4} \cdot \frac{\lambda^2}{r^2}$.

Say, now, that the diameter of the coil is six times the length of the needle, as in the case of our galvanometer, then the maximum error possible is

$$\frac{15}{4} \times \frac{1}{36} = 0{\cdot}104$$

or 10 % about.

APPENDIX II.

TABLE OF TANGENTS FOR EVERY QUARTER DEGREE.

Angle.		Tan.	Angle.		Tan.	Angle.		Tan.	Angle.		Tan.	Angle.		Tan.
Deg.	Mts.		Deg.	Mts.		Deg.	Mts.		Deg.	Mts.		Deg.	Mts.	
0	0	0·0000	18	0	0·3249	36	0	0·7265	54	0	1·376	72	0	3·078
	15	0·0044		15	0·3298		15	0·7332		15	1·389		15	3·124
	30	0·0087		30	0·3346		30	0·7400		30	1·402		30	3·172
	45	0·0131		45	0·3395		45	0·7467		45	1·415		45	3·221
1	0	0·0175	19	0	0·3443	37	0	0·7536	55	0	1·428	73	0	3·271
	15	0·0218		15	0·3492		15	0·7604		15	1·441		15	3·323
	30	0·0262		30	0·3541		30	0·7673		30	1·455		30	3·376
	45	0·0306		45	0·3590		45	0·7743		45	1·469		45	3·431
2	0	0·0349	20	0	0·3640	38	0	0·7813	56	0	1·483	74	0	3·487
	15	0·0393		15	0·3689		15	0·7883		15	1·497		15	3·546
	30	0·0437		30	0·3739		30	0·7954		30	1·511		30	3·606
	45	0·0480		45	0·3789		45	0·8026		45	1·525		45	3·668
3	0	0·0524	21	0	0·3839	39	0	0·8098	57	0	1·540	75	0	3·732
	15	0·0568		15	0·3889		15	0·8170		15	1·555		15	3·798
	30	0·0612		30	0·3939		30	0·8243		30	1·570		30	3·867
	45	0·0655		45	0·3990		45	0·8317		45	1·585		45	3·938
4	0	0·0699	22	0	0·4040	40	0	0·8391	58	0	1·600	76	0	4·011
	15	0·0743		15	0·4091		15	0·8466		15	1·616		15	4·087
	30	0·0787		30	0·4142		30	0·8541		30	1·632		30	4·165
	45	0·0831		45	0·4193		45	0·8617		45	1·648		45	4·247
5	0	0·0875	23	0	0·4245	41	0	0·8693	59	0	1·664	77	0	4·331
	15	0·0919		15	0·4296		15	0·8770		15	1·681		15	4·419
	30	0·0963		30	0·4348		30	0·8847		30	1·698		30	4·511
	45	0·1007		45	0·4400		45	0·8925		45	1·715		45	4·606
6	0	0·1051	24	0	0·4452	42	0	0·9004	60	0	1·732	78	0	4·705
	15	0·1095		15	0·4505		15	0·9083		15	1·750		15	4·808
	30	0·1139		30	0·4557		30	0·9163		30	1·767		30	4·915
	45	0·1184		45	0·4610		45	0·9244		45	1·786		45	5·027
7	0	0·1228	25	0	0·4663	43	0	0·9325	61	0	1·804	79	0	5·145
	15	0·1272		15	0·4716		15	0·9407		15	1·823		15	5·267
	30	0·1317		30	0·4770		30	0·9490		30	1·842		30	5·396
	45	0·1361		45	0·4823		45	0·9573		45	1·861		45	5·530
8	0	0·1405	26	0	0·4877	44	0	0·9657	62	0	1·881	80	0	5·671
	15	0·1450		15	0·4931		15	0·9742		15	1·901		15	5·820
	30	0·1495		30	0·4986		30	0·9827		30	1·921		30	5·976
	45	0·1539		45	0·5040		45	0·9913		45	1·942		45	6·140
9	0	0·1584	27	0	0·5095	45	0	1·000	63	0	1·963	81	0	6·314
	15	0·1629		15	0·5150		15	1·009		15	1·984		15	6·497
	30	0·1673		30	0·5206		30	1·018		30	2·006		30	6·691
	45	0·1718		45	0·5261		45	1·027		45	2·028		45	6·897
10	0	0·1763	28	0	0·5317	46	0	1·036	64	0	2·050	82	0	7·115
	15	0·1808		15	0·5373		15	1·045		15	2·073		15	7·348
	30	0·1853		30	0·5430		30	1·054		30	2·097		30	7·596
	45	0·1899		45	0·5486		45	1·063		45	2·120		45	7·861
11	0	0·1944	29	0	0·5543	47	0	1·072	65	0	2·145	83	0	8·144
	15	0·1989		15	0·5600		15	1·082		15	2·169		15	8·449
	30	0·2035		30	0·5658		30	1·091		30	2·194		30	8·777
	45	0·2080		45	0·5715		45	1·101		45	2·220		45	9·131
12	0	0·2126	30	0	0·5774	48	0	1·111	66	0	2·246	84	0	9·514
	15	0·2171		15	0·5832		15	1·120		15	2·273		15	9·931
	30	0·2217		30	0·5890		30	1·130		30	2·300		30	10·39
	45	0·2263		45	0·5949		45	1·140		45	2·328		45	10·88
13	0	0·2309	31	0	0·6009	49	0	1·150	67	0	2·356	85	0	11·43
	15	0·2355		15	0·6068		15	1·161		15	2·385		15	12·03
	30	0·2401		30	0·6128		30	1·171		30	2·414		30	12·71
	45	0·2447		45	0·6188		45	1·181		45	2·444		45	13·46
14	0	0·2493	32	0	0·6249	50	0	1·192	68	0	2·475	86	0	14·30
	15	0·2540		15	0·6310		15	1·202		15	2·507		15	15·26
	30	0·2586		30	0·6371		30	1·213		30	2·539		30	16·35
	45	0·2633		45	0·6432		45	1·224		45	2·571		45	17·61
15	0	0·2679	33	0	0·6494	51	0	1·235	69	0	2·605	87	0	19·08
	15	0·2726		15	0·6556		15	1·246		15	2·639		15	20·82
	30	0·2773		30	0·6619		30	1·257		30	2·675		30	22·90
	45	0·2820		45	0·6682		45	1·268		45	2·711		45	25·45
16	0	0·2867	34	0	0·6745	52	0	1·280	70	0	2·747	88	0	28·64
	15	0·2915		15	0·6809		15	1·292		15	2·785		15	32·73
	30	0·2962		30	0·6873		30	1·303		30	2·824		30	38·19
	45	0·3010		45	0·6937		45	1·315		45	2·864		45	45·83
17	0	0·3057	35	0	0·7002	53	0	1·327	71	0	2·904	89	0	57·29
	15	0·3105		15	0·7067		15	1·339		15	2·946		15	76·39
	30	0·3153		30	0·7133		30	1·351		30	2·989		30	114·6
	45	0·3201		45	0·7199		45	1·364		45	3·033		45	229·2
												90	0	∞

APPENDIX III.

TABLES FOR FACILITATING THE COMPUTATION OF THE RESISTANCE OF BATTERIES.

The formula generally used for calculating battery resistances when using a Tangent Galvanometer is

$$f = \frac{\tan a'^{\circ}}{\tan a^{\circ} - \tan a'^{\circ}} w' - g$$

Put $z = \frac{\tan a'^{\circ}}{\tan a^{\circ} - \tan a'^{\circ}} = \frac{\sin a'^{\circ} \cos a^{\circ}}{\sin (a^{\circ} - a'^{\circ})} = \sin a'^{\circ} \cos a^{\circ} \operatorname{cosec} (a^{\circ} - a'^{\circ})$.*

Then $$f = z\, w' - g.$$

2. In these tables will be found z calculated for nearly all possible deflections with the tangent galvanometer. The angles given in the left-hand column are the deflections a° obtained when no external resistance is unplugged, and those in the top column are the deflections a'° obtained through *any* external resistance w'. All the remaining numbers are the calculated values of z.

3. An example will make the use of the tables clear. Suppose the deflections obtained through the thick coil of the tangent galvanometer, the resistance of which is $g =$ say 1 *ohm*, to be

$a^{\circ} = 40^{\circ}$, no external resistance unplugged,

and $a'^{\circ} = 15^{\circ}$, an external resistance of 200 unplugged.

By referring to page 237, opposite the angle 40° in the left-hand column and directly under the angle 15° in the top column, will be found the figures 0·469, the corresponding value of z.

$$\therefore \quad f = 0{\cdot}469 \times 200 - 1$$
$$= 92{\cdot}8$$

4. In taking reversed "readings" the *mean* of the two "readings" *right* and *left* will often contain half a degree. In this case the *mean* of the two nearest values of z will approximate to the true z, thus—

$$\left.\begin{array}{ll} \text{If } a^{\circ} = 70^{\circ} \textit{ right} \text{ and } a'^{\circ} = 32^{\circ}, & z = 0{\cdot}294 \\ \text{and} \quad a^{\circ} = 71^{\circ} \textit{ left} \text{ and } a'^{\circ} = 32, & z = 0{\cdot}274 \end{array}\right\} \text{ Mean} = 0{\cdot}284$$

$$\therefore \quad f = 0{\cdot}284 \times 200 - 1 = 55{\cdot}8.$$

The ordinary method of calculation (p. 14) gives 55·9.

5. Similarly, when both a° and a'° contain a fraction, the *mean* of the two *means* will approximate to the correct z. But, generally, where great accuracy is required the calculations had better be made in the usual way, and recourse not had to the tables.

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* These forms are convenient for calculating by logarithms. The following table has been recalculated for this edition by means of the third formula. As the calculation of the table is very laborious, it has only been done once. It therefore probably contains errors. Any reader detecting a mistake is requested to notify the same to the author.

TABLE FOR CALCULATING BATTERY RESISTANCES.

	5°	6°	7°	8°	9°	10°	11°	12°	13°	14°	15°	16°	17°	18°
20°	0·316	0·406	0·509	0·629	0·770	0·940	1·146	1·404	1·735	2·175	2·791			
21°	·295	·377	·470	·578	·702	·850	1·026	1·241	1·509	1·853	2·312	2·952		
22°	·276	·352	·437	·533	·645	·774	0·927	1·110	1·333	1·612	1·969	2·445	3·110	
23°	·260	·329	·407	·495	·595	·711	·845	1·003	1·192	1·424	1·712	2·082	2·575	3·264
24°	·245	·309	·381	·461	·552	·656	·775	0·918	1·077	1·273	1·511	1·809	2·192	2·701
25°	·231	·291	·357	·431	·514	·608	·715	·838	0·981	1·149	1·351	1·597	1·904	2·298
26°	·219	·275	·336	·405	·481	·566	·663	·772	·899	1·046	1·219	1·427	1·680	1·996
27°	·207	·260	·317	·381	·451	·529	·617	·716	·828	0·958	1·107	1·287	1·500	1·760
28°	·197	·246	·300	·359	·424	·496	·576	·666	·767	·883	1·016	1·171	1·353	1·571
29°	·187	·234	·285	·340	·400	·466	·540	·622	·714	·817	0·936	1·072	1·230	1·416
30°	·179	·223	·270	·322	·378	·440	·508	·583	·666	·760	·866	0·987	1·126	1·287
31°	·170	·212	·257	·305	·358	·415	·467	·547	·624	·709	·805	·913	1·036	1·177
32°	·163	·202	·245	·290	·339	·393	·451	·515	·586	·664	·751	·848	0·958	1·083
33°	·156	·193	·233	·276	·323	·373	·427	·487	·552	·623	·702	·791	·890	1·001
34°	·149	·185	·223	·263	·307	·354	·405	·460	·520	·586	·659	·740	·829	0·929
35°	·143	·177	·213	·251	·292	·336	·384	·436	·492	·553	·620	·693	·775	·866
36°	·137	·169	·203	·240	·279	·320	·365	·414	·466	·522	·584	·652	·726	·809
37°	·131	·162	·195	·229	·266	·305	·348	·393	·442	·494	·552	·614	·683	·758
38°	·126	·155	·187	·219	·254	·291	·331	·374	·419	·469	·522	·580	·643	·712
39°	·121	·149	·179	·210	·243	·278	·316	·356	·399	·445	·494	·548	·607	·670
40°	·116	·143	·171	·201	·233	·266	·301	·339	·380	·423	·469	·519	·560	·632
41°	·112	·137	·164	·193	·223	·254	·288	·324	·362	·402	·446	·492	·543	·597
42°	·108	·132	·160	·185	·213	·243	·280	·309	·345	·383	·424	·474	·514	·565
43°	·103	·127	·148	·177	·205	·233	·263	·295	·329	·365	·403	·444	·488	·533
44°	·0996	·122	·146	·170	·197	·223	·252	·282	·314	·348	·384	·422	·463	·507
45°	·0959	·117	·140	·163	·188	·214	·241	·270	·300	·332	·366	·402	·440	·481
46°	·0923	·1130	·1345	·1570	·1806	·2052	·2311	·2583	·2869	·3171	·3491	·3829	·4189	·4572
47°	·0888	·1087	·1293	·1508	·1733	·1968	·2214	·2472	·2744	·3029	·3331	·3650	·3988	·4347
48°	·0855	·1045	·1243	·1449	·1663	·1887	·2122	·2367	·2624	·2895	·3180	·3480	·3798	·4135
49°	·0823	·1006	·1195	·1392	·1597	·1810	·2033	·2267	·2511	·2767	·3037	·3320	·3620	·3936

TABLE FOR CALCULATING BATTERY RESISTANCES—*continued.*

	19°	20°	21°	22°	23°	24°	25°	26°	27°	28°	29°	30°	31°
20°													
21°													
22°													
23°													
24°	3·412												
25°	2·823	3·557											
26°	2·401	2·941	3·696										
27°	2·084	2·501	3·055	3·832									
28°	1·838	2·170	2·596	3·164	3·958								
29°	1·640	1·912	2·252	2·688	3·269	4·082							
30°	1·478	1·706	1·984	2·331	2·777	3·370	4·199						
31°	1·342	1·536	1·769	2·053	2·406	2·861	3·466	4·311					
32°	1·227	1·395	1·593	1·829	2·118	2·478	2·941	3·557	4·417				
33°	1·129	1·275	1·446	1·647	1·887	2·181	2·547	3·017	3·643	4·517			
34°	1·043	1·175	1·321	1·494	1·693	1·942	2·240	2·611	3·088	3·723	4·611		
35°	0·967	1·082	1·213	1·364	1·539	1·746	1·994	2·295	2·672	3·156	3·799	4·699	
36°	·901	1·004	1·120	1·258	1·405	1·583	1·792	2·042	2·348	2·729	3·218	3·870	4·781
37°	·841	0·934	1·038	1·156	1·290	1·444	1·623	1·835	2·088	2·397	2·782	3·277	3·935
38°	·788	·872	0·966	1·071	1·190	1·325	1·480	1·661	1·875	2·130	2·442	2·831	3·330
39°	·740	·816	·901	0·996	1·102	1·221	1·370	1·514	1·697	1·912	2·165	2·484	2·876
40°	·696	·766	·843	·929	1·023	1·130	1·251	1·388	1·546	1·730	1·946	2·206	2·522
41°	·656	·720	·791	·868	0·954	1·050	1·157	1·278	1·416	1·575	1·760	1·978	2·238
42°	·619	·678	·743	·814	·892	0·978	1·074	1·182	1·304	1·442	1·602	1·787	2·006
43°	·585	·640	·700	·765	·835	·914	1·000	1·097	1·205	1·327	1·460	1·622	1·812
44°	·554	·605	·660	·719	·782	·855	0·934	1·020	1·117	1·225	1·347	1·487	1·647
45°	·5252	·572	·623	·678	·738	·802	·874	0·952	1·039	1·135	1·244	1·366	1·505
46°	·4981	·542	·589	·640	·695	·754	·819	·890	0·947	1·055	1·152	1·260	1·382
47°	·4729	·514	·557	·604	·655	·710	·769	·834	·905	0·983	1·070	1·166	1·274
48°	·4493	·488	·528	·572	·617	·669	·724	·783	·848	·918	0·996	1·088	1·179
49°	·4272	·463	·501	·541	·585	·631	·682	·736	·795	·859	·930	1·008	1·093

TABLE FOR CALCULATING BATTERY RESISTANCES—*continued.*

	32°	33°	34°	35°	36°	37°	38°	39°	40°	41°	42°	43°	44°
20°													
21°													
22°													
23°													
24°													
25°													
26°													
27°													
28°													
29°													
30°													
31°													
32°													
33°													
34°													
35°													
36°													
37°	4·856												
38°	3·995	4·924											
39°	3·379	4·049	4·986										
40°	2·917	3·423	4·098	5·041									
41°	2·557	2·953	3·463	4·141	5·090								
42°	2·268	2·587	2·986	3·498	4·179	5·131							
43°	2·031	2·294	2·602	3·014	3·527	4·211	5·166						
44°	1·833	2·053	2·316	2·637	3·038	3·552	4·237	5·194					
45°	1·666	1·852	2·072	2·336	2·657	3·058	3·572	4·257	5·215				
46°	1·522	1·682	1·868	2·088	2·351	2·674	3·073	3·587	4·272	5·229			
47°	1·396	1·535	1·695	1·881	2·101	2·364	2·684	3·084	3·597	4·280	5·236		
48°	1·286	1·408	1·547	1·706	1·892	2·110	2·372	2·692	3·090	3·602	4·283	5·236	
49°	1·189	1·296	1·418	1·555	1·714	1·899	2·117	2·378	2·696	3·093	3·602	4·280	5·229

TABLE FOR CALCULATING BATTERY RESISTANCES—*continued.*

	5°	6°	7°	8°	9°	10°	11°	12°	13°	14°	15°	16°	17°
50°	0·0792	0·0967	0·1149	0·1337	0·1533	0·1736	0·1949	0·2171	0·2403	0·2656	0·2901	0·3168	0·3451
51°	·0762	·0930	·1104	·1284	·1471	·1666	·1868	·2079	·2299	·2530	·2771	·3024	·3290
52°	·0734	·0895	·1061	·1233	·1412	·1598	·1791	·1991	·2201	·2419	·2648	·2887	·3138
53°	·0706	·0860	·1020	·1184	·1355	·1532	·1716	·1907	·2106	·2318	·2530	·2756	·2993
54°	·0679	·0827	·1002	·1137	·1300	·1469	·1645	·1826	·2015	·2212	·2417	·2632	·2856
55°	·0653	·0794	·0942	·1091	·1247	·1409	·1575	·1749	·1928	·2115	·2310	·2512	·2724
56°	·0627	·0763	·0903	·1047	·1196	·1350	·1509	·1674	·1844	·2022	·2206	·2398	·2598
57°	·0602	·0733	·0866	·1004	·1146	·1293	·1445	·1601	·1764	·1932	·2107	·2288	·2477
58°	·0578	·0703	·0831	·0963	·1098	·1238	·1383	·1532	·1686	·1846	·2011	·2183	·2362
59°	·0555	·0674	·0797	·0922	·1052	·1185	·1322	·1464	·1611	·1762	·1919	·2082	·2250
60°	·0532	·0646	·0763	·0883	·1006	·1133	·1264	·1399	·1538	·1682	·1830	·1984	·2144
61°	·0510	·0619	·0730	·0845	·0962	·1083	·1208	·1336	·1468	·1604	·1744	·1890	·2041
62°	·0488	·0592	·0698	·0808	·0920	·1035	·1153	·1274	·1399	·1528	·1661	·1799	·1941
63°	·0467	·0566	·0667	·0771	·0878	·0987	·1099	·1215	·1333	·1455	·1581	·1711	·1845
64°	·0446	·0540	·0637	·0736	·0837	·0941	·1047	·1157	·1269	·1384	·1503	·1626	·1752
65°	·0425	·0515	·0607	·0701	·0797	·0896	·0997	·1100	·1206	·1316	·1428	·1543	·1663
66°	·0405	·0491	·0578	·0667	·0759	·0852	·0947	·1045	·1146	·1249	·1355	·1464	·1576
67°	·0386	·0467	·0550	·0634	·0721	·0809	·0899	·0992	·1086	·1184	·1283	·1386	·1491
68°	·0366	·0443	·0522	·0602	·0684	·0767	·0852	·0939	·1029	·1120	·1214	·1310	·1409
69°	·0347	·0420	·0495	·0570	·0647	·0726	·0806	·0888	·0972	·1061	·1146	·1237	·1330
70°	·0329	·0398	·0468	·0539	·0612	·0686	·0761	·0838	·0917	·0998	·1081	·1165	·1252
71°	·0311	·0375	·0441	·0508	·0577	·0646	·0717	·0790	·0864	·0939	·1016	·1096	·1177
72°	·0293	·0354	·0416	·0478	·0542	·0608	·0674	·0742	·0811	·0881	·0954	·1027	·1103
73°	·0275	·0332	·0390	·0449	·0509	·0570	·0632	·0695	·0759	·0825	·0892	·0961	·1031
74°	·0257	·0311	·0365	·0420	·0476	·0532	·0590	·0649	·0709	·0770	·0832	·0896	·0961
75°	·0240	·0290	·0340	·0391	·0443	·0496	·0549	·0604	·0659	·0716	·0774	·0832	·0892

TABLE FOR CALCULATING BATTERY RESISTANCES—*continued.*

	18°	19°	20°	21°	22°	23°	24°	25°	26°	27°	28°	29°
50°	0·3748	0·4063	0·440	0·475	0·513	0·553	0·596	0·643	0·693	0.747	0·806	0·870
51°	·3571	·3866	·418	·451	·486	·524	·564	·607	·653	·702	·756	·814
52°	·3402	·3680	·397	·428	·461	·496	·533	·573	·616	·661	·711	·764
53°	·3242	·3504	·378	·407	·438	·470	·505	·542	·581	·623	·668	·717
54°	·3090	·3336	·359	·387	·415	·446	·478	·512	·549	·588	·630	·674
55°	·2951	·3171	·342	·368	·394	·423	·450	·485	·519	·555	·593	·634
56°	·2807	·3025	·324	·349	·374	·401	·429	·459	·490	·524	·559	·597
57°	·2674	·2880	·309	·332	·356	·381	·407	·434	·464	·494	·527	·562
58°	·2548	·2741	·294	·316	·338	·361	·385	·411	·438	·467	·498	·530
59°	·2426	·2609	·280	·300	·321	·342	·365	·389	·414	·441	·470	·499
60°	·2309	·2481	·266	·285	·304	·325	·346	·368	·392	·417	·443	·471
61°	·2197	·2359	·253	·270	·289	·308	·328	·349	·370	·394	·418	·443
62°	·2088	·2241	·240	·256	·274	·291	·310	·330	·350	·372	·394	·418
63°	·1984	·2128	·228	·243	·259	·276	·293	·312	·331	·351	·372	·394
64°	·1879	·2018	·216	·230	·245	·261	·277	·294	·312	·331	·350	·370
65°	·1786	·1913	·204	·218	·232	·247	·262	·278	·294	·312	·330	·349
66°	·1691	·1811	·193	·206	·219	·233	·247	·262	·277	·293	·310	·328
67°	·1600	·1712	·183	·195	·207	·220	·233	·247	·261	·276	·291	·308
68°	·1511	·1616	·172	·184	·195	·207	·219	·232	·245	·259	·274	·289
69°	·1425	·1528	·162	·173	·184	·195	·206	·218	·230	·243	·256	·270
70°	·1341	·1433	·153	·162	·172	·183	·193	·204	·216	·228	·240	·253
71°	·1260	·1345	·143	·152	·162	·171	·181	·191	·202	·213	·224	·236
72°	·1180	·1260	·1341	·1425	·1511	·1600	·1691	·1786	·1883	·1984	·2088	·2197
73°	·1103	·1177	·1252	·1330	·1409	·1488	·1576	·1663	·1752	·1845	·1941	·2041
74°	·1028	·1090	·1165	·1237	·1310	·13 6	·1464	·1543	·1626	·1711	·1799	·1890
75°	·0954	·1016	·1081	·1146	·1214	·1283	·1355	·1428	·1503	·1581	·1661	·1744

TABLE FOR CALCULATING BATTERY RESISTANCES—*continued.*

	30°	31°	32°	33°	34°	35°	36°	37°	38°	39°	40°	41°
50°	0·940	1.017	1·102	1·197	1·304	1·424	1·562	1·720	1·903	2·120	2·379	2.696
51°	·878	0·948	1·024	1·109	1·204	1·310	1·429	1·565	1·722	1·905	2·120	2·378
52°	·822	·885	0·954	1·030	1·114	1·208	1·313	1.483	1·567	1·722	1·903	2·117
53°	.770	·827	·890	0·958	1·034	1·117	1·210	1·314	1·432	1·565	1·720	1·899
54°	·723	·775	·831	·893	0·961	1·036	1·118	1·210	1·313	1·429	1·562	1·714
55°	·679	·726	·778	.834	·895	0·962	1·036	1·117	1·208	1·310	1·425	1·555
56°	·638	·681	·729	·779	·835	·895	0·961	1·034	1·114	1·204	1·304	1·417
57°	·600	·640	·683	·729	·779	·834	·893	0·958	1·030	1·109	1·197	1·296
58°	·564	·601	·641	·683	·729	·778	·831	·890	0·954	1·024	1·102	1·189
59°	·531	·565	·601	·640	·681	·726	·775	·827	·885	0.948	1·017	1·093
60°	·500	·531	·564	·600	·638	·679	·723	·770	·822	·878	0·940	1·008
61°	·471	·499	·530	·562	·597	·634	·674	·717	·764	·814	·870	0·930
62°	·443	·469	·498	·527	·559	·593	·629	·668	·711	·756	·806	·859
63°	·417	·441	·467	·495	·524	·555	·588	·623	·661	·702	·747	·795
64°	·392	·415	·438	·464	·490	·519	·549	·581	·616	·653	·693	·736
65°	·368	·389	·411	·434	·459	·485	·512	·542	·573	·607	·643	·682
66°	·346	·365	·385	·407	·429	·453	·478	·505	·533	·564	·596	·631
67°	·325	·342	·361	·381	·401	·423	.446	·470	·496	·524	.558	·585
68°	·304	·321	·338	·356	·375	·395	·416	·438	·461	·486	·513	·541
69°	·285	·300	·316	·332	·349	·368	·387	·407	·428	·451	·475	·501
70°	·266	·280	·294	·309	·325	·342	·359	·378	·397	·418	·440	·463
71°	·249	·261	·274	·288	·303	·318	·334	·350	·368	·387	·406	·427
72°	·2309	·2426	·2548	·2674	·2807	·2945	·3090	·3242	·3402	·3571	·3748	·3936
73°	·2144	·2250	·2362	·2477	·2598	.2724	·2856	·2993	·3138	·3290	·3451	·3620
74°	·1984	.2082	·2183	.2288	.2398	.2512	·2632	·2756	·2887	·3024	·3168	·3320
75°	.1830	.1919	·2011	.2107	·2206	·2310	·2417	·2530	·2648	·2771	·2901	·3037

TABLE FOR CALCULATING BATTERY RESISTANCES—*continued.*

	42°	43°	44°	45°	46°	47°	48°	49°	50°	51°	52°	53°
50°	3·090	3·597	4.272	5·215								
51°	2·692	3·084	3·587	4·257	5·194							
52°	2·372	2·634	3·003	3·572	4·237	5·166						
53°	2·110	2·364	2·672	3·058	3·552	4·211	5·131					
54°	1·892	2·101	2·351	2·657	3·038	3·527	4·179	5·090				
55°	1·706	1·882	2·088	2·336	2·637	3·014	3·498	4·141	5·041			
56°	1·547	1·695	1·868	2·072	2·316	2·614	2·986	3·463	4·098	4·986		
57°	1·408	1·535	1·682	1·852	2·053	2·294	2·587	2·953	3·423	4·049	4·924	
58°	1·286	1·396	1·522	1·666	1·833	2·031	2·268	2·557	2·917	3·379	3·995	4·856
59°	1·179	1·274	1·382	1·505	1·647	1·812	2·006	2·238	2·522	2·876	3·330	3·935
60°	1·083	1·166	1·260	1·366	1·478	1·626	1·787	1·978	2·206	2·484	2·831	3·277
61°	0·996	1·070	1·152	1·244	1·347	1·466	1·602	1·760	1·946	2·170	2·442	2·782
62°	·918	0·983	1·055	1·135	1·225	1·327	1·442	1·575	1·730	1·912	2·130	2·453
63°	·848	·905	0·969	1·039	1·117	1·205	1·304	1·416	1·546	1·697	1·875	2·088
64°	·783	·834	·890	0·952	1·020	1·097	1·182	1·278	1·388	1·514	1·661	1·835
65°	·724	·769	·819	·873	0·934	1·000	1·074	1·157	1·251	1·358	1·480	1·623
66°	·669	·710	·754	·802	·855	0·914	0·978	1·050	1·130	1·221	1·325	1·444
67°	·619	·655	·695	·738	·784	·836	·892	0·954	1·024	1·102	1·190	1·290
68°	·572	·605	·640	·678	·719	·764	·814	·868	0·929	0·996	1·071	1·156
69°	·528	·557	·589	·623	·660	·700	·743	·791	·843	·901	0·966	1·038
70°	·487	·514	·542	·572	·605	·640	·678	·720	·766	·816	·872	0·934
71°	·449	·478	·498	·525	·554	·585	·619	·656	·696	·740	·788	·841
72°	·4135	·4347	·4572	·4813	·5071	·5348	·5646	·5969	·6319	·6701	·7120	·7580
73°	·3798	·3988	·4189	·4404	·4633	·4878	·5141	·5425	·5732	·6065	·6429	·6827
74°	·3480	·3650	·3829	·4020	·4223	·4440	·4673	·4922	·5191	·5482	·5798	·6143
75°	·3180	·3331	·3491	·3660	·3840	·4023	·4287	·4456	·4691	·4945	·5220	·5518

TABLE FOR CALCULATING BATTERY RESISTANCES—*continued.*

	54°	55°	56°	57°	58°	59°	60°	61°	62°	63°	64°	65°
50°												
51°												
52°												
53°												
54°												
55°												
56°												
57°												
58°												
59°	4·781											
60°	3·870	4·699										
61°	3·218	3·799	4·611									
62°	2·729	3·156	3·723	4·517								
63°	2·348	2·672	3·088	3·642	4·417							
64°	2·042	2·295	2·611	3·017	3·557	4·311						
65°	1·792	1·994	2·240	2·547	2·941	3·466	4·199					
66°	1·583	1·746	1·942	2·181	2·478	2·861	3·370	4·082				
67°	1·405	1·539	1·698	1·887	2·118	2·406	2·777	3·269	3·958			
68°	1·253	1·364	1·494	1·647	1·829	2·053	2·331	2·688	3·164	3·880		
69°	1·120	1·213	1·321	1·446	1·593	1·769	1·984	2·252	2·596	3·055	3·696	
70°	1·004	1·082	1·172	1·275	1·395	1·536	1·706	1·912	2·170	2·501	2·948	3·557
71°	0·901	0·967	1·043	1·129	1·227	1·342	1·478	1·640	1·838	2·084	2·401	2·823
72°	·809	·866	0·949	1·001	1·083	1·177	1·287	1·416	1·571	1·760	1·996	2·298
73°	·726	·775	·829	0·890	0·958	1·036	1·126	1·230	1·353	1·500	1·680	1·904
74°	·652	·693	·739	·791	·848	0·913	0·987	1·072	1·171	1·287	1·427	1·597
75°	·584	·620	·659	·702	·751	·805	·866	0·936	1·016	1·109	1·219	1·351

APPENDIX IV.

THE GALVANIC ELEMENT.

Voltaism, or Galvanism as it is generally called, forms in its direct application (galvanic batteries) the chief source for producing the electric current required for carrying on telegraphic communication. In 1790 Aloysius Galvani, a physician of Bologna, accidentally observed a most novel phenomenon which caused the greatest sensation throughout Europe. He noticed distinct convulsions in the prepared legs of a frog, suspended from a copper hook, whenever the legs came into contact with the iron railings to which the copper hook was fastened. Nine years later Count Alexander Volta explained this strange effect by the now well-known theory of "Contact Electricity," and, by his untiring energy, his searching investigations, and beautiful experiments, established "Voltaism" on a firm basis. On Volta's fundamental experiments all subsequent discoveries in this important branch have been made. In 1800, before the Paris Academy, he proved in the presence of Napoleon the First that the action observed by Galvani was due to nothing else but electricity, which Volta considered was produced by the contact of dissimilar metals. Hence the name *contact electricity.* It is not, however, within the scope of the present appendix to follow up step by step the development of Volta's celebrated discoveries, interesting as they may be; but only to state the general facts as Voltaism stands at present:—

Any combination of conducting bodies (one of which at least must be a compound substance), arranged in contact with each other so as to form a closed circuit, is capable of producing an electric current of definite strength and direction; and the development of the electric current is invariably accompanied by the chemical decomposition of at least one of the compound bodies that occur in the circuit.

Any such arrangement for producing an electric current has been called a "galvanic element," and the most simple form would therefore be two metals immersed in the same liquid. The liquid is called the electrolyte, the two metals inside the liquid the electrodes, and outside the liquid the poles of the element. For instance two dissimilar metals, say zinc and copper, both immersed in pure water form a galvanic element, which so soon as the circuit outside the water is

closed by any conductor (say a copper wire) connecting the zinc and copper (− and + poles of the galvanic element) will invariably produce an electric current, and also a decomposition of the water.

The electric current and the decomposition of the water co-exist invariably, and they cease when the circuit is broken. Many have been the theories suggested to explain this extraordinary phenomenon, and exciting and even bitter have been the discussions between opponents holding these different theories, but little have been the results; no real physical explanation has as yet been given, only the difficulties to be explained have shown themselves in a clearer light, and the true nature of the phenomenon remains almost as dark as it was in Alexander Volta's time. However, it seems to be a fact that though contact between dissimilar conducting substances is necessary to start the current, contact alone is not sufficient to keep up the current, which must be maintained by chemical action, or more generally by the transformation of some other kind of energy. But whatever may be the physical cause and true explanation of the galvanic current, for our purpose it is sufficient to know that we can produce a current by such a convenient arrangement as that of the galvanic cell. The only question to be solved is to select such conducting substances compound and simple, as will give a strong and constant current when arranged into an element. It was soon observed that in a galvanic element consisting of *two* metals and *one* compound liquid, the current produced became weaker the longer the circuit remained closed, and further that the decrease of current at any one moment was directly proportional to the strength of the current passing at that moment. This rapid decrease of current in a *one* liquid cell has been called "polarisation" of the element by its own current, and the action which actually takes place is twofold, *viz.*:—

Firstly:—A decrease of the original electromotive force.

Secondly:—An alteration of the internal resistance of the element. (This alteration is either an increase or decrease, depending entirely on the nature of the compound liquid used and the conducting bodies immersed.)

For instance, say we have immersed a copper and a zinc plate in pure water, then the chemical action which takes place so soon as the circuit is closed is as follows:—

The water is decomposed, the oxygen combines with the zinc to form oxide of zinc which adheres as an insoluble substance to the zinc, while the hydrogen goes to the copper and adheres to it in bubbles. Thus in this particular case the current is diminished, firstly, by the establishment of a secondary electromotive force (hydrogen and oxide of zinc) which acts in a direction opposite to that of the original electromotive force; secondly, by an increase of the internal resistance of the element on account of oxide of zinc being a worse conductor than metallic zinc, and hydrogen an insulator. Now, as far as the oxide of zinc is concerned, the addition of a small quantity of sul-

phuric acid to the pure water would certainly keep the zinc clean, on account of sulphate of zinc being then formed which is soluble in water in the place of the insoluble oxide of zinc. But this elimination of one defect would not produce any real practical benefit, since the quantity of hydrogen would be increased and would now act with a far greater energy.

In fact similar actions will invariably take place in any other known form of *one* liquid element. Hence, quite different galvanic combinations are required to obtain *constancy.*

It is clear that if, in the case of copper and zinc immersed in dilute sulphuric acid, the free hydrogen at the copper plate could be consumed the very moment it was set free, or, if instead of hydrogen being liberated, a conducting metal could be deposited on the copper plate, the problem of constancy would be solved.

In 1836 Professor Daniell achieved this by surrounding the copper plate with sulphate of copper, which is decomposed by the current, and the copper set free is deposited on the copper plate. Since then, the problem of producing a constant E. M. F. by certain galvanic combinations has been solved in very different ways, and in most cases equally successfully, but none of them have had such an extended application, especially in telegraphy, as Daniell's cell or some of its numerous modifications.

The essential parts of a Daniell's cell are:—

1. A copper plate immersed in a solution of sulphate of copper.
2. A zinc plate immersed in a solution of sulphate of zinc.
3. Some arrangement to keep the two liquids from mixing with one another.

The modifications of Daniell's cell that have been made necessarily depend solely on the different fulfilment of condition (3), and the special construction adopted.

The E. M. F. of a galvanic element depends mostly on the nature of the two conducting bodies forming the electrodes, and slightly on the nature of the compound liquids, while the internal resistance depends slightly on the two conducting bodies immersed, and mostly on the *nature* and *concentration* of the two compound liquids. While both E. M. F. and internal resistance are functions of the temperature not as yet accurately determined. Thus the constancy of the current from a Daniell's cell would be kept up, supposing that the third condition is fulfilled, if during working in the first instance the two metals copper and zinc did not undergo any alteration, and in the second instance the two solutions kept entirely constant in concentration. These two conditions are very nearly fulfilled in a Daniell's cell, if sufficient care be taken, *i.e.*, pure metals be used, a sufficient quantity of crystals of sulphate of copper be placed in the solution to keep it concentrated, and if pure water be often added to the solution of sulphate of zinc.

To understand what takes place in a galvanic cell it may be useful to examine the changes which occur during the decomposition of a compound—such as hydrochloric acid—by an electric current. If two platinum plates, connected with the poles of a galvanic battery, are

introduced into a vessel containing dilute hydrochloric acid, decomposition at once takes place, hydrogen gas being evolved at the platinum plate in connection with the zinc of the battery and chlorine being liberated at the other or positive plate. While this action is going on, there is no evolution of gas in any part of the intermediate liquid; moreover, there is not even visible movement if proper precautions are taken to prevent circulation. It is obvious, therefore, that although the hydrogen and chlorine are evolved in atomic proportions, they cannot have come from the same molecules of hydrochloric acid. To explain the phenomenon it is usually supposed that there is a decomposition of the molecules of the compound throughout the liquid between the plates, so that when chlorine is evolved at the positive plate the hydrogen with which it was previously combined unites with the chlorine of the neighbouring molecules, that the hydrogen of these unites with the chlorine of the next, and so on until the hydrogen of the molecules in contact with the negative plate finding no chlorine to unite with it, and being attracted by the negative plate, is set free and escapes. If instead of using two platinum plates connected with a battery, two plates, one of zinc and the other of platinum connected by a metallic wire, are immersed in dilute hydrochloric acid, the acid is decomposed, hydrogen being evolved on the platinum plate whilst the zinc is dissolved. In this case the chlorine combines with the zinc, forming chloride of zinc, and the hydrogen with which it was previously combined unites with the chlorine of the neighbouring molecules, and so on until the platinum plate is reached, where the hydrogen, finding no chlorine with which it can unite, is set free on the surface of the plate. If now the hydrochloric acid is replaced by sulphuric acid perfectly similar effects are produced, the zinc uniting with the group SO_4 of the sulphuric acid forming sulphate of zinc, whilst the hydrogen of the acid is evolved on the platinum.

In a Daniell's cell charged with a dilute solution of sulphate of zinc in contact with the zinc plate and a concentrated solution of sulphate of copper in contact with the copper plate, it is found that the zinc plate is gradually dissolved and the copper plate coated with an equivalent quantity of metallic copper. In this case the zinc unites with the SO_4 of the molecules of sulphate of zinc in contact with it, and the zinc with which it was previously combined unites with the SO_4 of the neighbouring molecules, and so on until the solution of sulphate of copper is reached, here the zinc combines with the SO_4 of the molecules of sulphate of copper, and the copper of these molecules combine with the SO_4 of the next, and so on until the copper of the sulphate in contact with the copper plate is thrown down in the metallic state.

Thus the final result in a Daniell's cell will be:—The consumption of zinc and sulphate of copper, the formation of sulphate of zinc, and the deposition of pure copper.

APPENDIX V.

RECORDING OF BATTERY TESTS.

THE tables annexed illustrate the manner in which battery tests are to be recorded.

All the tests of every battery, from the tests of the several cells composing it in the battery room, are to be included in the record, so that it will present a complete history of each battery. To each battery a sufficient number of consecutive pages in the register is to be allotted. The form is arranged so that each page will contain the daily tests of one month.

1. In Table 1 the tests of a standard cell are given. The deflection it gives throughout the month are seen to be very constant, which should always be the case with a standard.

2. Table 2 exhibits the tests made in the battery room of 20 local cells, whose resistance has been reduced to the requisite extent, preparatory to connecting them up to form a local battery to work sounders.

In Table 3 we have the tests for one month of the same cells after they have been connected up to form a battery consisting of four compound elements in series each with five times the surface of a single element. It will be noticed that the several cells composing the compound cells are grouped according to their resistances, thus all in the 1st compound cell have a resistance of 9·29 ohms, all in the 2d compound cell 8·70 ohms, and so on. Further we see that the resistance of the battery, as measured in the battery room (= 6·99 ohms), agrees sufficiently closely with the resistance calculated from the known resistances of the several cells, *viz*:—

$$\tfrac{1}{5}\,(9{\cdot}29 + 8{\cdot}70 + 8{\cdot}99 + 9{\cdot}30) = 7{\cdot}256 \text{ ohms.}$$

The slight increase in resistance observed when the battery is tested in the signal room (= 7·14) is due to the introduction of the leading wires, &c., into the circuit. Also the E. M. F. of the battery in terms of that of the standard cell (= 3.98) approximates to the number (= 4) of cells *in series*.

3. Table 4 gives the tests in the battery room of 20 line cells that have been brought into working order, preparatory to their being

joined up to form a line battery. The resistance of every cell is less than 30 ohms and the E. M. F. is good.

Table 5 gives the tests of the same cells after they have been connected up all in series to form a line battery of 20 elements. We notice that the battery as measured in the battery room (= 587·2 ohms), whilst the known resistance of the several cells gives

$$8 \times 26{\cdot}9 + 12 \times 27{\cdot}7 = 546 \text{ ohms.}$$

This difference would, however, be accounted for by an error of reading, of half a degree in the measurement of the separate cells. We see also that the E. M. F. of the battery in terms of that of the standard cell (= 20·06) approximates to the number (= 20) of elements in the battery.

Finally we observe the decrease in resistance as the month advances both in the local and in the line batteries, while the E. M. F. remains sensibly constant.

TABLE 1.—Standard Cell.

Date.	No. of cells tested.	Name of cell or cells.	Thin Coil. R=0	Thin Coil. R=2000	Thick Coil. R=0	Thick Coil. R=20	Thick Coil. R=200	Resistance Absolute. Per cell.	E. M. F. in terms of the standard cell.	Remarks.
1874. April 1st	1	S. cell.	67·5°	...	43°	25°	...	19·00	1·00	Selected as the standard and placed in its box in Signal Room.
	1	"	67·5°	...	43°	...	...	...	...	
" 2d	1	"	67·5°	...	43°	...	...	...	...	
" 3d	1	"	67·5°	...	43°	...	...	...	...	
" 4th	1	"	67·5°	...	43°	...	...	...	...	
" 5th	1	"	67·5°	...	43°	...	...	...	...	
" 6th	1	"	67·5°	...	43°	...	...	...	...	
" 7th	1	"	67·5°	...	43°	..	...	...	...	
" 8th	1	"	67·5°	...	43°	...	...	...	...	
" 9th	1	"	67·5°	...	43°	...	...	...	...	
" 10th	1	"	67·5°	...	43°	...	...	...	...	
" 11th	1	"	67·5°	...	43°	...	...	...	...	
" 12th	1	"	67·5°	...	43°	...	...	...	...	
" 13th	1	"	67·5°	...	43°	...	...	...	...	
" 14th	1	"	67·5°	...	43°	...	...	...	...	
" 15th	1	"	67·5°	...	43°	...	...	...	...	
" 16th	1	"	67·5°	...	43°	...	...	...	...	
" 17th	1	"	67·5°	...	43°	...	...	...	...	
" 18th	1	"	67·5°	...	43°	...	...	...	...	
" 19th	1	"	67·5°	...	43°	...	...	...	...	
" 20th	1	"	67·5°	...	43°	...	...	...	...	
" 21st	1	"	67·5°	...	43°	...	...	...	...	
" 22d	1	"	67·5°	...	43°	...	...	...	...	
" 23d	1	"	67·5°	...	43°	...	...	...	...	
" 24th	1	"	67·5°	...	43°	...	...	...	...	
" 25th	1	"	67·5°	...	43°	...	...	...	...	
" 26th	1	"	67·5°	...	43°	...	...	...	...	
" 27th	1	"	67·5°	...	43°	...	...	...	...	
" 28th	1	"	67·5°	...	43°	...	...	...	...	
" 29th	1	"	67·5°	...	43°	..	...	...	...	
" 30th	1	"	67·5°	...	43°	...	...	...	...	

TABLE 2.

Local Battery for 5 Instruments of about 30 Ohms each.

Date.	No. of cells tested.	Name of cell or cells.	Thin Coil.		Thick Coil.			Resistance Absolute. Per cell	E. M. F. in terms of the standard cell.	Remarks.
			R=0	R=2000	R=0	R=20	R=200			
1874.										In Battery Room.
April 1st	1	1*a*	69°	...	61°	31·5°	...	9·29	0·99	
" "	1	1*b*	69°	...	61°	31·5°	...	9·29	0·99	
" "	1	1*c*	69°	...	61°	31·5°	...	9·29	0·99	Compound cell No. 1.
" "	1	1*d*	69°	...	61°	31·5°	...	9·29	0·99	
" "	1	1*e*	69°	...	61°	31·5°	...	9·29	0·99	
" "	1	2*a*	68°	...	60·5°	30°	...	8·70	0·94	
" "	1	2*b*	68°	...	60·5°	30°	...	8·70	0·94	
" "	1	2*c*	68°	...	60·5°	30°	...	8·70	0·94	Compound cell No. 2.
" "	1	2*d*	68°	...	60·5°	30°	...	8·70	0·94	
" "	1	2*e*	68°	...	60·5°	30°	...	8·70	0·94	
" "	1	3*a*	69°	...	61°	31°	...	8·99	0·99	
" "	1	3*b*	69°	...	61°	31°	...	8·99	0·99	
" "	1	3*c*	69°	...	61°	31°	...	8·99	0·99	Compound cell No. 3.
" "	1	3*d*	69°	...	61°	31°	...	8·99	0·99	
" "	1	3*e*	69°	...	61°	31°	...	8·99	0·99	
" "	1	4*a*	69°	...	60·5°	31°	...	9·30	0·99	
" "	1	4*b*	69°	...	60·5°	31°	...	9·30	0·99	
" "	1	4*c*	69°	...	60·5°	31°	...	9·30	0·99	Compound cell No. 4.
" "	1	4*d*	69°	...	60·5°	31°	...	9·30	0·99	
" "	1	4*e*	69°	...	60·5°	31°	...	9·30	0·99	

TABLE 3.

Local Battery for 5 Instruments of about 30 Ohms each.

Date.	No. of cells tested.	Name of cell or cells.	Thin Coil. R = 0	Thin Coil. R = 2000	Thick Coil. R = 0	Thick Coil. R = 20	Thick Coil. R = 200	Resistance Absolute. / Per cell.	E. M. F. in terms of the standard cell.	Remarks.
1874.										
April 1st	20	1a e to 4a e	...	28·5°	69·25°	87°	...	6·99 / 8·74	3·98	In Battery Room.
„ „	„	„	...	28·5°	69°	87°	...	7·14 / 8·92	3·98	In Signal Room. Probable length of the leading wire from the battery room is fifty yards.
„ 2d	„	„	...	28·5°	69·25°	...	...	...	...	
„ 3d	„	„	...	28·5°	69·25°	...	...	...	...	
„ 4th	„	„	...	28·5°	69·25°	...	...	...	...	In Signal Room.
„ 5th	„	„	...	28·5°	69·5°	87°	...	6·85 / 8·56	3·98	do.
„ 6th	„	„	...	28·5°	69·5°	...	...	...	...	do.
„ 7th	„	„	...	28·5°	69·5°	...	...	...	...	do.
„ 8th	„	„	...	28·5°	69·5°	...	...	...	...	do.
„ 9th	„	„	...	28·5°	69·75°	...	...	...	...	do.
„ 10th	„	„	...	28·5°	69·75°	...	...	...	...	do.
„ 11th	„	„	...	28·5°	69·75°	...	...	...	...	do.
„ 12th	„	„	...	28·5°	70°	87·25°	...	6·65 / 8·31	3·98	do.
„ 13th	„	„	...	28·5°	70°	...	...	...	...	do.
„ 14th	„	„	...	28·5°	70°	...	...	...	...	do.
„ 15th	„	„	...	28°	70·25°	...	...	...	...	do.
„ 16th	„	„	...	28°	70°	...	...	...	...	do.
„ 17th	„	„	...	27°	69°	...	...	...	...	do.
„ 18th	„	„	...	26°	68°	...	...	...	...	In Signal Room. Zincs changed.
„ 19th	„	„	...	29°	70·5°	87·25°	...	6·37 / 7·96	4·06	In Signal Room.
„ 20th	„	„	...	29°	70·5°	...	...	...	...	do.
„ 21st	„	„	...	29°	70·5°	...	...	...	...	do.
„ 22d	„	„	...	29°	70·5°	...	...	...	...	do.
„ 23d	„	„	...	29°	70·75°	...	...	...	...	do.
„ 24th	„	„	...	29°	70·75°	...	...	...	...	do.
„ 25th	„	„	...	29°	70·75°	...	...	...	...	do.
„ 26th	„	„	...	29°	70·75°	...	...	...	...	do.
„ 27th	„	„	...	29°	70·75°	...	...	...	...	do.
„ 28th	„	„	...	29°	70·75°	...	...	...	...	do.
„ 29th	„	„	...	29°	71°	87·5°	...	6·18 / 7·72	4·16	do.
„ 30th	„	„	...	29°	71°	...	...	...	...	do.

TABLE 4.—No. *x* Line Battery.

Date.	No. of cells tested.	Name of cell or cells.	Thin Coil. R = 0	Thin Coil. R = 2000	Thick Coil. R = 0	Thick Coil. R = 20	Thick Coil. R = 200	Resistance Absolute. Per cell.	E. M. F. in terms of the standard cell.	Remarks.
1874.										In Battery Room.
April 1st	1	1	66°	...	32°	20°	...	26·90	0·99	
" "	1	2	66°	...	32°	20°	...	26·90	0·99	
" "	1	3	66°	...	32°	20°	...	26·90	0·99	
" "	1	4	66°	...	32°	20°	...	26·90	0·99	
" "	1	5	66°	...	32°	20°	...	26·90	0·99	
" "	1	6	66°	...	32°	20°	...	26·90	0·99	
" "	1	7	66°	...	32°	20°	...	26·90	0·99	
" "	1	8	66°	...	32°	20°	...	26·90	0·99	
" "	1	9	65·5°	...	31°	19·5°	...	27·70	0·97	
" "	1	10	65·5°	...	31°	19·5°	...	27·70	0·97	
" "	1	11	65·5°	...	31°	19·5°	...	27·70	0·97	
" "	1	12	65·5°	...	31°	19·5°	...	27·70	0·97	
" "	1	13	65·5°	...	31°	19·5°	...	27·70	0·97	
" "	1	14	65·5°	...	31°	19·5°	...	27·70	0·97	
" "	1	15	65·5°	...	31°	19·5°	...	27·70	0·97	
" "	1	16	65·5°	...	31°	19·5°	...	27·70	0·97	
" "	1	17	65·5°	...	31°	19·5°	...	27·70	0·97	
" "	1	18	65·5°	...	31°	19·5°	...	27·70	0·97	
" "	1	19	65·5°	...	31°	19·5°	...	27·70	0·97	
" "	1	20	65·5°	...	31°	19·5°	...	27·70	0·97	

TABLE 5.—No. x Line Battery.

Date.	No. of cells tested.	Name of cell or cells.	Thin Coil. R = 0	Thin Coil. R = 2030	Thick Coil. R = 0	Thick Coil. R = 20	Thick Coil. R = 2 0	Resistance Absolute. / Per cell.	E. M. F. in terms of the standard cell.	Remarks.
1874.				Degs.	Degs.		Degs.			
April 1st	20	1 to 20	...	65	32	...	25	587·2 / 29·36	20·06	In Battery Room.
	,,	,,	...	65	32	...	25	587·2 / 29·36	20· 6	In Signal Room.
,, 2d	,,	,,	...	65	33	...	...	...	...	Ditto.
,, 3d	,,	,,	...	65	34	...	...	...	...	do.
,, 4th	,,	,,	...	65	34·5	...	...	...	...	do.
,, 5th	,,	,,	...	65·5	35	...	27	533.8 / 26·69	21·08	do.
,, 6th	,,	,,	...	65·5	35	...	...	...	...	do.
,, 7th	,,	,,	...	65·5	35·5	...	...	...	...	do.
,, 8th	,,	,,	...	65·5	36	...	...	...	...	do.
,, 9th	,,	,,	...	65·5	36	...	...	...	...	do.
,, 10th	,,	,,	...	65·5	37	...	...	...	...	do.
,, 11th	,,	,,	...	65·5	37	...	...	...	...	do.
,, 12th	,,	,,	...	66	37·5	...	28·5	483·3 / 24·16	20·19	do.
,, 13th	,,	,,	...	66	37 5	...	...	...	...	do.
,, 14th	,,	,,	...	66	38	...	...	...	...	do.
,, 15th	,,	,,	...	65	38	...	...	...	...	do.
,, 16th	,,	,,	...	64	38	...	...	...	...	do.
,, 17th	,,	,,	...	63	37	...	...	...	...	do.
,, 18th	,,	,,	...	62	35	...	...	...	...	do. Zincs changed.
,, 19th	,,	,,	...	66	40	...	30	440 5 / 22 02	19·86	do.
,, 20th	,,	,,	...	66	41	...	...	..	...	do. At 7 hrs. 30 min.
*,, 20th	,,	,,	1°	...	...	...	...	...	...	At 11 hrs. 5 min.
,, 20th	,,	,,	...	66	41	...	...	...	...	do. At 11 hrs. 10 min.
,, 21st	,,	,,	...	66	41	...	...	...	...	do.
,, 22d	,,	,,	...	66	41	...	...	...	...	do.
,, 23d	,,	,,	...	66	41·5	...	...	...	...	do.
,, 24th	,,	,,	...	66	42	...	...	...	...	do.
,, 25th	,,	,,	...	66	42	...	...	...	...	do.
,, 26th	,,	,,	...	66·5	42·5	...	31·5	403·0 / 20·15	20·04	do.
,, 27th	,,	,,	...	66·5	42·5	...	...	...	...	do.
,, 28th	,,	,,	...	66·5	43	...	...	...	...	do.
,, 29th	,,	,,	...	66·5	43	...	...	...	...	do.
,, 30th	,,	,,	...	66·5	44	...	...	...	...	do.

* At 11 hrs. 8 min. work stopped on x line as we could not get distant station. Battery tested at commutator and found defective. Battery tested in battery room: gave a deflection of only 1° through thin coil with no resistance in circuit, proving a discontinuity to probably exist. Each cell tested separately: cell No. 9 gave no deflection. Another cell introduced in its place, whole battery retested in signal room and found perfect. Duration of interruption 7 minutes. On examination of cell No. 9, the insulated wire was found broken inside the cell. At the moment of the interruption the battery man was wiping the stand of the x line battery, and must have accidentally moved cell No. 9 and thrown a strain on to the wire, which caused the discontinuity to appear.

APPENDIX VI.

ON THE ELECTRICAL RESISTANCE OF THE EARTH.

SUPPOSE a perfectly conducting spherical electrode A of radius r to be placed at the centre of a second electrode B, consisting of a perfectly conducting spherical shell of greater radius R, and that the space between the two electrodes A and B be occupied by a uniformly conducting substance of conductivity k, then the electrical resistance between the two electrodes can be easily calculated, since in this case we may assume the lines of flow to be normal to the surfaces of the electrodes.

About the common centre of the two electrodes describe one sphere of radius x (greater than r but smaller than R), and a second of radius $x+\delta x$. Then the resistance of the spherical shell enclosed between x and $x+\delta x$ is

$$\delta w = \frac{\delta x}{4 k \pi x^2}$$

Hence, the total resistance between the two electrodes is

$$w = \frac{1}{4 k \pi} \int_r^R \frac{dx}{x^2} = \frac{1}{4 k \pi}\left(\frac{1}{r} - \frac{1}{R}\right)$$

and, for any other two similar electrodes A' B', of radii r' R' respectively,

$$w' = \frac{1}{4 k' \pi}\left(\frac{1}{r'} - \frac{1}{R'}\right)$$

If we connect the inner electrodes A A' of the two systems together through a resistance x, and the outer electrodes B B' through a resistance y, the resistance z between the two inner electrodes will clearly be the parallel resistance of the two paths open to the current, *i.e.*,

$$z = \frac{x\,(w + w' + y)}{x + w + w' + y}$$

If now we suppose the radii R R' to become greater and greater, w and w' approach the limits

$$w = \frac{1}{4 k \pi r} \qquad w' = \frac{1}{4 k' \pi r'}$$

and at the limit $R = R' = \infty$, the two inner electrodes A A' will be in an infinite uniformly conducting field, when necessarily $k = k'$, $y = o$, and putting $x = \infty$, we have $z = w + w'$.

Therefore

$$z = \frac{1}{8 k \pi}\left(\frac{1}{r} + \frac{1}{r'}\right)$$

When $\qquad r' = r$

$$z = \frac{1}{4 k \pi r}$$

the formula given by Smaasen (Pogg: Ann: Vol. lxxii., p. 448) for the resistance between two equal spherical electrodes placed in an infinite uniformly conducting field. If we imagine the conducting field to be cut by an infinite plane passing through the centres of the electrodes A A', and consider only the conducting field on the one side of this plane, then the electrodes will be hemispheres and the resistance between them will obviously be double of the above, *i.e.*,

$$z = \frac{1}{4 k \pi}\left(\frac{1}{r} + \frac{1}{r'}\right)$$

since there are only half the number of paths now open to the current.

The case of an infinite body bounded on the one side by an infinite plane, in which two electrodes are placed, approximately represents that of the earth as employed in telegraphy. Hence the expression for the resistance between two *earths* consists of two terms, each of which is the resistance between one finite electrode and another electrode of infinite size situated at an infinite distance. If, therefore, we define the resistance of *one* earth-plate to be the resistance offered by our planet between that earth-plate and another earth-plate of very great size situated at a very great distance, we are justified in putting the resistance between two earth-plates equal to the sum of the resistances of the single earth-plates. Further, if the electrodes be not *hemispheres* but *plates* buried in the surface of the earth, the resistance z will not be altered provided we make the surfaces of the plates equal to the surfaces of the hemispheres, *i.e.*,

$$q = \pi r^2$$

and

$$q' = \pi r'^2$$

Whence

$$r = \sqrt{\frac{q}{\pi}}$$

and

$$r' = \sqrt{\frac{q'}{\pi}}$$

$$z = \frac{1}{4k\sqrt{\pi}}\left(\frac{1}{\sqrt{q}} + \frac{1}{\sqrt{q'}}\right)$$

This formula shows that the resistance between two earth-plates is independent of their distance apart, and varies inversely as the square root of their area.

By experiments, specially made in Calcutta, in 1869, it has been found that actually the resistance between a pair of plates of the departmental size is independent of the distance they are put apart even at very small distances; and that actually the resistance between a pair of plates decreases more slowly than directly with the surface of the plates, and does so apparently proportionally to the square root of that area. It is extremely difficult, however, to make measurements of this sort accurately, on account of the influence of the natural current between the plates, and of other accidental influences not easy of control.

As the flow of current between any two electrodes in contact with a body of very large dimensions takes place in peculiar curves all of which terminate at the electrodes, it will be clear that at or near each electrode the current flowing through the unit section must be greatest. Hence the absolute conductivity of the body at or near the electrodes must have the greatest effect in altering the resistance between the two electrodes. By placing, therefore, the plates in a good conducting substance, such as mud saturated with water, or by artificially surrounding each plate by good conducting substances such as charcoal, coke, &c., we can most decidedly decrease the resistance of the earth between the electrodes. On the other hand it will be clear that after having ascertained the resistance of *one* electrode, and further knowing its surface in contact with the earth we can always calculate k, the average conductivity of the earth, which must represent very closely the average conductivity of the planet at the locality of the electrode. If that calculated conductivity is very high, we may conclude that the planet at the spot must consist of good conducting substances, and supposing that the methods of measurement are accurate and that the many accidental influences still inherent could safely be eliminated, then the method of measuring the resistance of an earth might give the geologist very valuable information of the kind of strata at the spot where the measurements have been taken.

For instance our Indian experience has shown that the resistance of an earth-plate of departmental size (42" × 32") at different places in India varies far more than the resistance of an earth-plate in the same locality at different periods. Further we have found that as a general rule the resistance of an earth-plate of departmental size is smaller than 10 B. A. U. Only a few exceptions have come to notice, as at Bellary where the resistance was much higher, and could only be reduced by

increasing the size of the plate. At Raneegunge where coals prevail in abundance, the resistance of the earth is exceedingly small, scarcely more than half a unit. In order to give an example how to calculate the absolute conductivity k of the earth, we will take it for granted that the resistance of an earth-plate $42'' \times 32''$ is never greater than 10 ohms.

Now

$$z = \frac{1}{4k\sqrt{\pi q}}$$

Therefore

$$10 = \frac{1}{4k\sqrt{3 \cdot 14 \times 32 \times 42}}$$

where the inch is the unit of length.

$$10 = \frac{0 \cdot 3937}{4k\sqrt{3 \cdot 14 \times 32 \times 42}}$$

where the centimetre is the unit of length.

Hence

$$k = \frac{0 \cdot 3937}{40\sqrt{3 \cdot 14 \times 32 \times 42}} \text{ B. A. U.}$$

$$= \frac{0 \cdot 3937}{40 \times 10^9\sqrt{3 \cdot 14 \times 32 \times 42}} \text{ C. G. S. U.*}$$

$$k = \frac{1}{660 \times 10^{10}} \text{ C. G. S. U. approximately,}$$

or the average conductivity of the earth in India is about $\frac{1}{92}$ of that of pure water at

$$22^\circ \text{ C.} \left(= \frac{1}{7 \cdot 18 \times 10^{10}} \text{ C. G. S. U.}\right)$$

This value of k must of course be considered a minimum.

As the resistance offered by a plate in contact with the ground does not only depend on the average conductivity of the ground at or near the plate, but also on how perfect the contact between ground and plate in each of its points is made, it is difficult to get true values of k for the different localities. The effect of this error will of course be reduced by increasing the size of earth-plates, and further by soaking the ground at or near the plate with water before the actual measurements are taken.

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[1] Centimetre gramme second units.

APPENDIX VII.

APPLICATION OF THE INSULATING MIXTURE TO BOBBINS AND COILS.*

THE empty bobbins are first thoroughly dried for about five hours at a temperature of not less than 230° F. The moment the bobbins are taken out of the oven, they are plunged into the melted mixture (ten parts, by weight, of yellow resin to one part of white wax) which should have a temperature of about 350° F. It will be observed that bubbles arise out of each bobbin after immersion, and when they cease the pan containing the mixture is to be removed from the oven, and the mixture, with the bobbins in it, allowed to cool down slowly. Just before the mixture begins to solidify the bobbins are removed.

The bobbins are next replaced in the oven, where any superfluous mixture drops off. When the bobbins look quite clean they are taken out of the oven, and, after having cooled down, are ready for coiling the wire on.

After the bobbins are filled with wire they have to undergo the very same process as just described for the empty bobbins—*i.e.*, drying at a temperature of not less than 230° F., and immersion in the melted mixture at about a temperature of 350° F.

Practice has shown that wire coils have to undergo this process at least three times in order to be quite certain that the mixture penetrates. Care is to be taken that in each of these successive heatings and immersions of the coils, the temperature does not rise too high, as otherwise the mixture already penetrated would exude instead of being soaked in. In other words, the temperature for drying should be kept at about 230° F., and that of the mixture should be somewhat lowered for each successive immersion.

No paper is to be interposed between the layers of wire. The requisite uniformity must be got by careful coiling. The paper, besides reducing the magnetic force of the coil, would also prevent the mixture from penetrating the coil.

In order that no error in the process described above may be made, it should be remembered that:—

* These instructions are given for the workshops, and for manufacturers who may have to make instruments for the Government Telegraph Department in India.

1. The preparatory drying of the bobbins and coils is necessary to drive out all air and moisture, so that the mixture may be able to penetrate. The temperature 230° F. is high enough for this purpose.

2. The immediate immersion of the bobbins or coils in the melted mixture, directly after removal from the drying oven, is necessary in order to avoid the entrance of fresh air and moisture.

3. The slow cooling of the bobbins and coils, while in the mixture, is necessary in order that only the mixture, and not air or moisture, is soaked in when contraction by cooling takes place.

4. The bobbins or coils must be left each time in the mixture until the bubbles cease, since this is the only test we have that the mixture has entered all the pores and crevices.

Oven.

The same oven is used for heating the coils and the mixture.

Several drawers, made of copper, fit into a box of the same metal.

This box is filled with oil which is heated, and produces a uniform temperature in the drawers in which the bobbins, coils, &c., are placed for drying. Each drawer has a tin grating, on which the bobbins, &c., are put without touching the bottom of the drawer. The pan containing the insulating mixture is heated directly by the fire of the oven.

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